Low Velocity Impact, Ultrasonic C-Scan and Compression After Impact of Kenaf/Jute Hybrid Composites

K. Tabrej, M. T. H. Sultan, M. Jawaid, A. U. M. Shah, and S. Sani

Abstract The current research will discuss on the low velocity impact properties of kenaf/jute/kenaf hybrid composites treated with sodium hydroxide solution. The after impact damage properties will be observed through ultrasonic C-scan and compression after impact analyses. Kenaf/jute/kenaf sequence with 30 wt% fibre loading was laid up in epoxy matrix and cured in room temperature. The hybrid composites can withstand up to 30 J impact energy without full penetration, but appeared to be severely damaged. The visual inspection through the naked eyes clearly shown the cracks propagated towards the sides of the samples. However, limitations occurred through the C-scan technique, as the damages captured were not fully in parallel to the visual inspection. This is due to the properties of natural fibres. The compression after impact testing showed a maximum force of 42 kN needed to break the samples, impacted with low impact energy. The maximum compression force reduced as the impact energy increased.

Keywords Natural fibers · Kenaf · Jute · Hybrid composites · Low velocity impact

---

K. Tabrej · M. T. H. Sultan (✉) · A. U. M. Shah
Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia
e-mail: thariq@upm.edu.my

M. T. H. Sultan · M. Jawaid · A. U. M. Shah
Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia

M. T. H. Sultan
Aerospace Malaysia Innovation Centre (944751-A), Prime Minister's Department, MIGHT Partnership Hub, Jalan Impact, 63000 Cyberjaya, Selangor Darul Ehsan, Malaysia

S. Sani
Industrial Technology Division, Malaysian Nuclear Agency, 43000 Kajang, Selangor, Malaysia

M. T. H. Sultan et al. (eds.), *Impact Studies of Composite Materials*, Composites Science and Technology, https://doi.org/10.1007/978-981-16-1323-4_6

1 Introduction

Kenaf and jute natural fibers are much famous now as an alternative to synthetic (Barari et al. 2016), and both fibers have some good and bad advantages such as kenaf and jute are very much eco-friendly, the cheap cost to making products etc. (Omrani et al. 2016). and the disadvantages such as poor compatibilities in petroleum-based polymers compared to synthetic fibre reinforcements (Aji et al. 2013). The researcher is trying to find out the way to the enhancement of properties of natural kenaf/jute hybrid composites (Ferdous and Hossain 2017). The hydrophilicity decreases the adhesion to the polymer matrix, thus decreasing the performance of the obtained composites (Ku et al. 2011). Chemical modifications on natural fibers can decrease its hydrophilic properties and improve the compatibilities between the matrix and fibers (Pickering et al. 2016). Previous studies suggested chemical modification on natural fibres such as alkali and silane treatment (John and Anandjiwala 2008). In this study, sodium hydroxide (NaOH) fibers treatment was applied to improve the compatibilities of kenaf/jute hybrid composites.

Hybrid is one of the alternative techniques to improve the disadvantages of single type composites. There are natural-natural, natural-synthetic and synthetic-synthetic types of hybrid composites (Gholizadeh 2018; Luo 2016). To reduce the percentage of synthetic materials in composites, natural-natural hybrid is the best alternative (Jothibasu et al. 2018). Various combinations of natural-natural hybrid composites were reported to study their mechanical, thermal, physical and impact properties (Mansor et al. 2013). Studies on kenaf and jute as individual reinforcement in polymer matrix composites had been initiated by some researcher few years back. However, the hybrid of these two fibres was not yet reported to date. This is one of the gap that can be explored to suggest more potential applications of the hybrid composites (Ali et al. 2017; Selver et al. 2016).

Damages in composites can be analysed through destructive and non-destructive methods. Ultrasonic C-scan is one of the promising techniques to evaluate damages in laminated composites. However, its use in natural fibre composites is very limited. The concept of relative attenuation ultrasonic waves is applied in this technique. A transducer is used to scan the materials with the help of water as the transmission medium between both surfaces. Comparison between the relative attenuation and the operator-set level will results in colored images to display the damages of composites (Rahman et al. 2015). Besides matrix cracking, ultrasonic C-scan is also able to detect voids and delamination of composites (Ibrahim 2016). The ability of this technique to detect interlaminar damages in composites suggests its use in various fields (Dubary et al. 2018). This method is mostly suggested for the quality control in the production line of product development (Segreto et al. 2018).

Compared to tension and bending forces, low velocity impact cause higher risk to the strength and durability of composite structures. This is due to the sudden force applied in a very short time on the structure, which results in unpredictable damages (Razali et al. 2019). Due to that, compression after impact (CAI) testing is an excellent technique suggested to examine the residual strength of the impacted composite. However, this method is a destructive evaluation method, which needs to be done during the development and characterization stage of the materials and not applied on the complex structure of respective applications (Safri et al. 2019). Previous studies suggested a good correlation between the level of impact energy and the residual compressive strength of sugar palm/glass hybrid composites, which the residual strength reduced as the impact energy increases (Safri et al. 2019). Similar trend was also observed on the kenaf/glass hybrid composites using woven type fibres (Ismail et al. 2019). The breaking point during the compression after impact testing generally more concentrated at the centre, where the samples were impacted during the low velocity impact (Shahzad 2019). The severity of damage highly affects the residual strength and the damage pattern during the compression after impact testing (Sasikumar et al. 2019). Samples with bigger damage area, but less depth of damage are easier to be compressed compared to samples having smaller damage area with thicker depth (Khan et al. 2018a, b).

The current study aims to analyse the low velocity impact properties of treated kenaf/jute hybrid composites. The impact damages will be observed through visual inspection and ultrasonic C-scan, while the residual strength will be analysed through compression after impact testing.

2 Methodology

2.1 Materials

In the current study, woven mat kenaf and jute fibres were supplied by Indersen Shamlal Pvt. Ltd. India while Epoxamite 100 with 102 medium hardeners, brand Smooth-On, were purchased from Mecha Solve Engineering Sdn. Bhd, Selangor, Malaysia. The epoxy and hardener were mixed at a ratio of 3:1 as per datasheet provided. Table 1 showed the properties of Kenaf and Jute fibres.

Table 1 Properties of kenaf and Jute Fibers (Khan et al. 2018a, b)

Properties	Kenaf fiber	Jute fiber
Density	1.4	1.3
Tensile's strength	930	393–773
Young's modulus	20	26.5
Elongation at break (%)	1.6	1.5–1.8
Cellulose content (%)	53–11	58–63
Hemicellulose content (%)	15–19	12%
Lignin content (%)	05–11	12–14

2.2 *Preparation of Composites*

All the woven kenaf and jute fibres used in this study were immersed in a 6% NaOH solution for 2 h a room temperature. The fibres were then washed with running tap water and oven-dried at 80 °C for 24 h. The kenaf/jute hybrid composites were fabricated in a total of 9 layers with three layers each at the sequence of KKK/JJJ/KKK. This hybrid composites were fabricated using hand lay-up method and cured at room temperature for 24 h.

3 Low Velocity Impact Test

Low velocity impact testing was performed using the Imatek IM1-C Drop Weight Testing Machine, at the Laboratory of Aerospace Structure, UPM, as shown in Fig. 1. All results obtained from the low velocity impact tests were generated using Imatek's software. This computer software works together with impact tester and data acquisition system. Five impact energy levels of 10, 15, 20, 25, and 30 J, were applied in this study.

These energy levels (in Joules) were selected based on the preliminary tests conducted to obtain the range of energy reasonable for the whole actual impact testing. The energy levels more than 30 J lead to ultimately break the specimen. Low-velocity impact test was completed on the kenaf/jute hybrid composites with five repetitions of the impact energy of each sample. The drop mass of the hemispherical steel impactor of 5.101 kg and the tip diameter of 16 mm remains constant during the impact testing. All tests were performed on the specimens with sizes of 100 mm × 150 mm × 8.30 mm, according to ASTM (D7136, 2015). Equation (1) was applied to obtain the height of impactor based on the required impact energy.

$$\text{Imapact energy, } E_i = mgh \tag{1}$$

where,

m Total mass of the impactor, 5.101 kg
g Gravitational acceleration, 9.81 m/s^2
h Height of the impactor.

4 Ultrasonic C-Scan

The damage area of all the impacted samples were observed using the ultrasonic C-scan. The procedures were carried out at Malaysian Nuclear Agency, Bangi, Selangor using the R-Theta Arm scanner and RθScan software. Transducer with capacity of

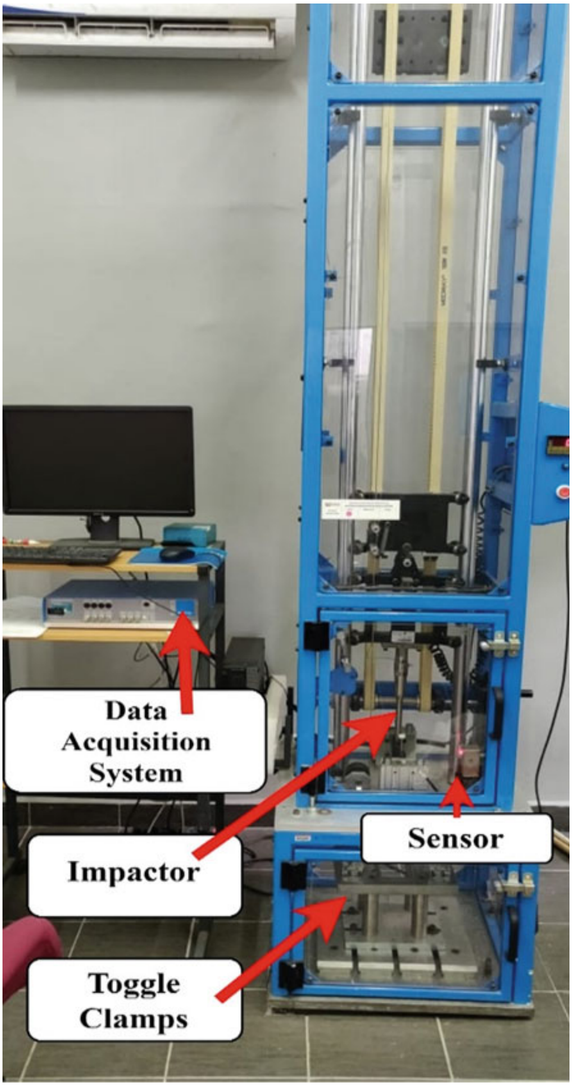


Fig. 1 Drop test rig instrument for low-velocity impact testing

1 MHz was used, together with SONATEST gel as couplant agent. The procedures were shown in Fig. 2.

5 Compression After Impact

Compression after impact (CAI) testing was conducted at Universiti Teknologi Malaysia (UTM), Kuala Lumpur. The test was performed according to ASTM

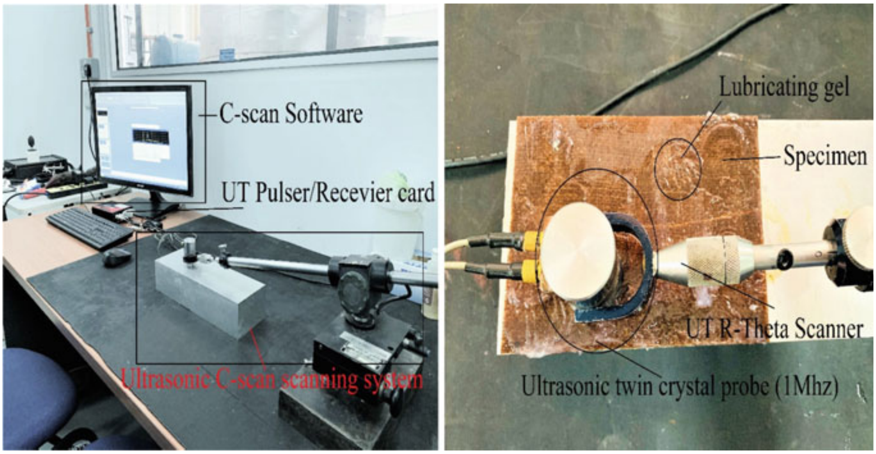


Fig. 2 The ultrasonic C-scan set up

(D7137, 2012) standard for assessing the compressive strength after the impact for a sample size of 100 × 150 mm. The CAI investigation was carried out by using the Universal Testing Machine (UTM) with 300 kN maximum load capacity. The typical crosshead speed displacement rate was 0.5 mm/min. Figure 3 shows the experimental set up for the compression after impact testing. A specific jig was used to hold the samples in upright position while the compressive load was applied equally the top side of the impacted samples until it breaks.

6 Results and Discussions

In this study, the analysis of low velocity impact properties were discussed in two different curves, which are force–displacement and force–time curves respectively.

6.1 Force Versus Displacement

The severity of damage on specimens during the low velocity impact test can be understood from the graph of force–displacement as shown in Fig. 4. The impactor movement and the deformation of the specimens impacted on the surface during interaction with the impactor are described in terms of the displacement. All samples showed the same trend at 10–30 J. As in Fig. 4, the closed curve obtained from the graph of force–displacement specified the specimens are being tested for the incomplete penetration damage on the test specimens. Indirectly, this clarified that low velocity full impactor penetration produced an open curve in the force–displacement

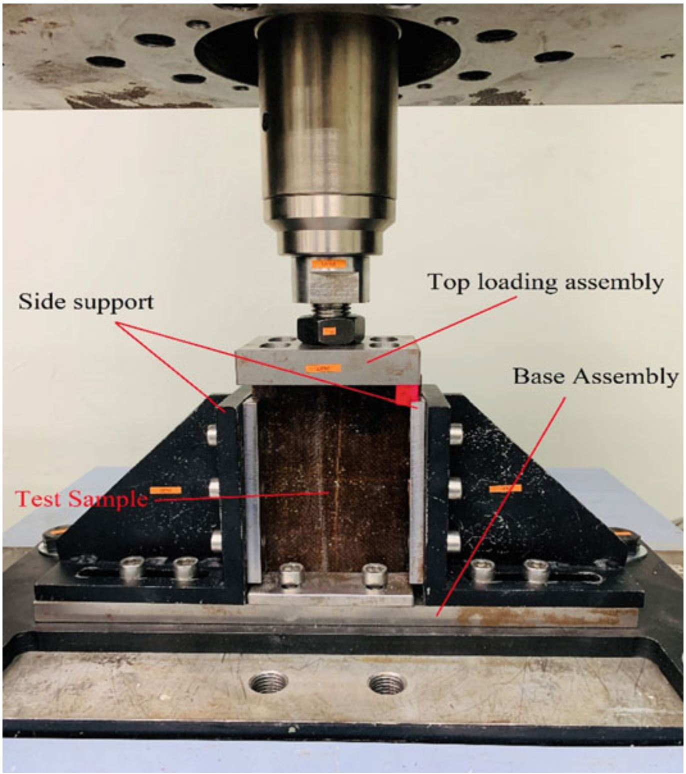
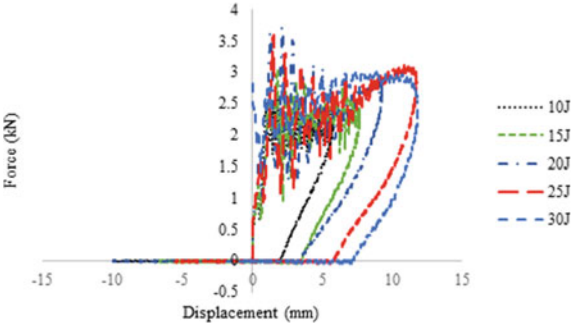


Fig. 3 The compression after impact test set up

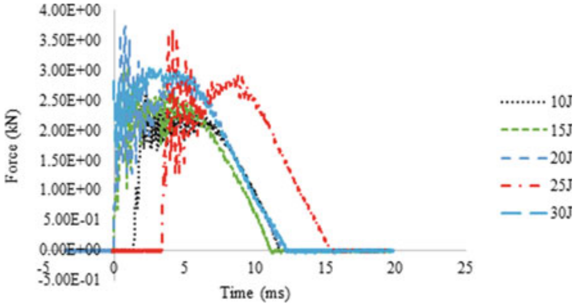
Fig. 4 Force versus displacement graph for woven kenaf/jute hybrid composites



graph. The upward and downward sections of the closed curve described the loading and unloading region respectively. The upward component also delivered the data about the sufficient bending stiffness on the sample (Salleh et al. 2013).

Moreover, another additional observation was the energy absorbed by the specimens. This value is significant to the area under this force–displacement graph. The

Fig. 5 Force versus time graph for woven kenaf/jute hybrid composites



kinetic energy transferred from the impactor to the specimens was absorbed in the form of damage initiations. In this study, kenaf as the outer layer act as protector to the jute in the inner layer. The displacement showed increasing value with the increase of impact energy levels (Campo 2008). The increase in displacement had increased the area under the graph, which in parallel to the more severe damage occurred for samples impacted with higher impact energy (Maleque et al. 2012).

6.2 Force Versus Time

The force–time curves in Fig. 5 showed the continuous rough and unsymmetrical shape from the beginning of sample fractured until damage (Yaghoobi and Fereidoon 2018). The area where the sample begins to fracture was indicated before the peak load and the propagation of the fracture was indicated beyond the peak load. For the kenaf/jute composites, the loading curve increased proportionately until a sawtooth-like curve was established at peak force before unloading occurred. From the graph, the force shifted in the curved slope beyond the first peak force fell due to the reduction in material stiffness for the kenaf/jute hybrid composite (Belingardi and Vadori 2002).

Initially, the kenaf/jute hybrid composite elastically behaved with minor failures like micro-cracking. Then, significant damaged occurred due to high force. The loading rate increased according to energy levels and significantly increased the force.

6.3 Ultrasonic C-Scan

Ultrasonic C-scan provided an appropriate analysis of the damage area of composites. In this study, the images from the ultrasonic C-scan were compared with the visual inspection from the naked eyes. Figure 7 shows the comparisons of damage area of

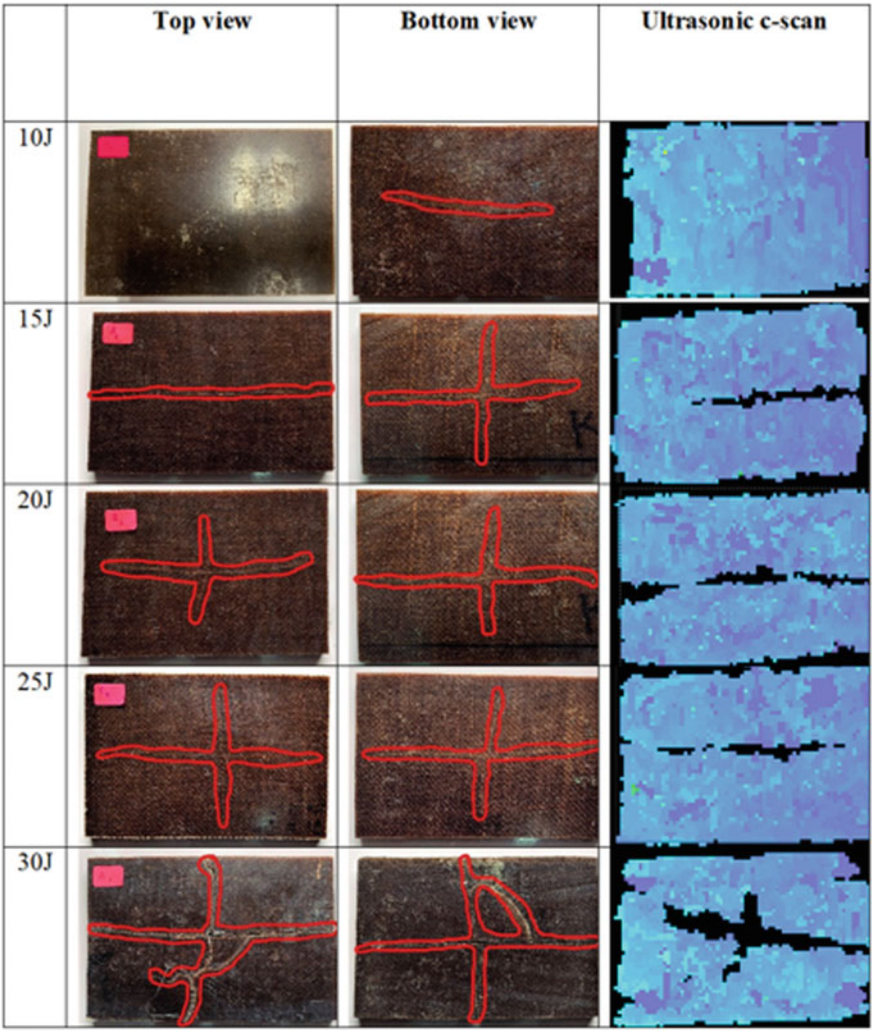


Fig. 7 Comparison of damage observations through visual inspection and images from ultrasonic C-scan

kenaf/jute hybrid composites impacted with respective energy levels of 10, 15, 20, 25, and 30 J.

All the five samples repetition for each energy level were scanned and analysed. However, only the most visible damages were compared in Fig. 7. In overall, the images from the C-scan technique did not showed a reliable data on the damage area. This is due to the natural fibres used as the reinforcement in composites, which absorbed the waves used in this technique. It can be suggested in the future, that the scanning procedure to be done several times on the surfaces of composites to collect more data and produce better images.

It can be seen the damage at the bottom surface of the sample impacted with 10 J impact energy could not be detected at all using the ultrasonic C-scan. Image produced for sample impacted at 15 J impact energy also displayed the damage on the top surface but missing for the bottom surface (Robinson and Davies 1992).

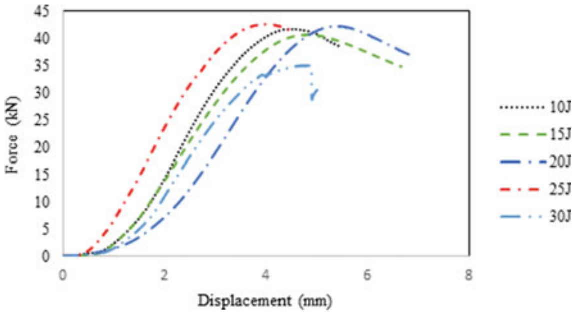
In terms of damage propagation in composites, it can be seen that matrix cracking initiated from the point of impact towards the sides of samples in a line and not scattered in numerous directions. This trend is one of the effects of using woven type fibres in composites. The woven fibres can reduce the chances of total failure, which the damages can be scattered in different directions from the point of impact. This condition normally happened on short fibre composites or random oriented long fibres composites. These two types of composites also have lower visibility of damages from the ultrasonic C-scan technique.

6.4 Compression After Impact (CAI)

The compression after impact (CAI) test is used to predict the residual strength of composites after they had been impacted with respective impact energy levels. Figure 8 shows the force–displacement graph of the samples for compression after impact testing.

In overall, it can be seen that the peak compression force to break the samples were in the similar range of approximately 40–42 kN, except for the sample impacted at 30 J as it experienced severe damages and nearly to total failure during the impact (Ghelli and Minak, 2011). The damage patterns as described in Sect. 6.3 showed a good relation to the CAI analysis. All samples experienced matrix cracking initiated from the center, which promotes failure of composites under compressive load at almost similar force.

Fig. 8 Compression force vs displacement of kenaf/jute hybrid composite



7 Conclusions

The current study highlights the low velocity impact properties of woven kenaf/jute hybrid composites, their damage analyses and residual strength after impact. The use of woven type fibres results in more consistent data in all the analyses conducted. The ability of these natural-natural hybrid composites to withstand high impact energy of 30 J can be contributed from the type of woven fibres and the NaOH treatment applied on the fibres to improve the compatibility in polymers. In overall, this study may contribute to a better potential development of natural fibre composites, without having synthetic fibres as hybrid. The key findings from the current study can be suggested as follows:

i. Kenaf/jute hybrid composites in the sequence of KKK/JJJ/KKK in epoxy matrix with a total thickness of approximately 8 mm can withstand maximum impact energy of 30 J through the drop test rig method.
ii. The KKK/JJJ/KKK hybrid composites did not show visible damage on the top surface at 10 J impact energy.
iii. The use of natural fibres in polymer composites limits the data collected in the ultrasonic C-scan technique, thus produced non-reliable images of damage in comparison to the visual inspection from the naked eyes.
iv. The damage patterns observed after the impact testing can be correlate with the data acquired from the compression after impact testing.
v. Increase in impact energy will increase the severity of damages, thus reduce the residual strength of composites.

Acknowledgements This work was supported by UPM under GPB grant, 9668200. The authors would like to express their gratitude and sincere appreciation to the Department of Aerospace Engineering, Universiti Putra Malaysia, and Laboratory of Bio-composite Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, UPM (HICOE) for the close collaboration in this research.

Conflict of Interests The authors declare that there is no conflict of interests regarding the publication of this paper.

References

Aji IS, Zainudin ES, Abdan K, Sapuan SM, Khairul MD (2013) Mechanical properties and water absorption behavior of hybridized kenaf/pineapple leaf fibre-reinforced high-density polyethylene composite. J Compos Mater 47(8):979–990

Ali MAEM, Soliman AM, Nehdi ML (2017) Hybrid-fiber reinforced engineered cementitious composite under tensile and impact loading. Mater Des 117:139–149

Barari B, Omrani E, Moghadam AD, Menezes PL, Pillai KM, Rohatgi PK (2016) Mechanical, physical and tribological characterization of nano-cellulose fibers reinforced bio-epoxy composites: an attempt to fabricate and scale the 'Green'composite. Carbohydr Polym 147:282–293

Belingardi G, Vadori R (2002) Low velocity impact tests of laminate glass-fiber-epoxy matrix composite material plates. Int J Impact Eng 27(2):213–229

Campo EA (2008) Selection of polymeric materials: how to select design properties from different standards. William Andrew

D7136, ASTM (2015) Standard test method for measuring the damage resistance of a fiber-reinforced polymer matrix composite to a drop-weight impact event.https://doi.org/10.1520/d7136_d7136m-15

D7137, ASTM (2012) Standard test method for compressive residual strength properties of damaged polymer matrix composite plates. https://doi.org/10.1520/d7137_d7137m-12

Dubary N, Bouvet C, Rivallant S, Ratsifandrihana L (2018) Damage tolerance of an impacted composite laminate. Compos Struct 206:261–271

Ferdous S, Hossain MS (2017) Natural fibre composite (NFC): new gateway for jute, kenaf and allied fibres in automobiles and infrastructure sector. World J Res Rev 5(3)

Ghelli D, Minak G (2011) Low velocity impact and compression after impact tests on thin carbon/epoxy laminates. Compos Part B Eng 42(7):2067–2079

Gholizadeh S (2018) A review of impact behaviour in composite materials. In: Paper presented at the proceedings of Academicsera 38th international conference

Ibrahim ME (2016) Nondestructive testing and structural health monitoring of marine composite structures. In: Marine applications of advanced fibre-reinforced composites. Elsevier, pp 147–183

Ismail MF, Sultan MTH, Hamdan A, Shah AUM, Jawaid M (2019) Low velocity impact behaviour and post-impact characteristics of kenaf/glass hybrid composites with various weight ratios. J Mater Res Technol 8(3):2662–2673

John MJ, Anandjiwala RD (2008) Recent developments in chemical modification and characterization of natural fiber-reinforced composites. Polym Compos 29(2):187–207

Jothibasu S, Mohanamurugan S, Vijay R, Lenin Singaravelu D, Vinod A, Sanjay MR (2018) Investigation on the mechanical behavior of areca sheath fibers/jute fibers/glass fabrics reinforced hybrid composite for light weight applications. J Indus Text 1528083718804207

Khan MZ, Nazir H, Yifei H, Hong S, Ahmed FU, Liu K (2018a) Mechanical properties of ambient cured high-strength plain and hybrid fiber reinforced geopolymer composites from triaxial compressive tests. Constr Build Mater 185:338–353

Khan T, Sultan H, Bin MT, Ariffin AH (2018b) The challenges of natural fiber in manufacturing, material selection, and technology application: a review. J Reinf Plast Compos 37(11):770–779. https://doi.org/10.1177/0731684418756762

Ku H, Wang H, Pattarachaiyakoop N, Trada M (2011) A review on the tensile properties of natural fiber reinforced polymer composites. Compos Part B Eng 42(4):856–873

Luo T (2016) Mechanical behavior of layered foam composite panels subjected to low velocity impact events

Maleque MA, Afdzaluddin A, Iqbal M (2012) Flexural and impact properties of kenaf-glass hybrid composite. Paper presented at the Advanced Materials Research

Mansor MR, Sapuan SM, Zainudin ES, Nuraini AA, Hambali A (2013) Hybrid natural and glass fibers reinforced polymer composites material selection using analytical hierarchy process for automotive brake lever design. Mater Des 51:484–492

Omrani E, Menezes PL, Rohatgi PK (2016) State of the art on tribological behavior of polymer matrix composites reinforced with natural fibers in the green materials world. Eng Sci Technol Int J 19(2):717–736

Pickering KL, Efendy MGA, Le TM (2016) A review of recent developments in natural fibre composites and their mechanical performance. Compos Part a Appl Sci Manuf 83:98–112

Rahman MM, Hosur M, Hsiao K-T, Wallace L, Jeelani S (2015) Low velocity impact properties of carbon nanofibers integrated carbon fiber/epoxy hybrid composites manufactured by OOA–VBO process. Compos Struct 120:32–40

Razali N, Sultan MT, Jawaid M (2019) Impact damage analysis of hybrid composite materials. In: Durability and life prediction in biocomposites, fibre-reinforced composites and hybrid composites. Elsevier, pp 121–132

Robinson P, Davies GAO (1992) Impactor mass and specimen geometry effects in low velocity impact of laminated composites. Int J Impact Eng 12(2):189–207

Safri SN, Sultan MT, Jawaid M, Majid MA (2019) Analysis of dynamic mechanical, low-velocity impact and compression after impact behaviour of benzoyl treated sugar palm/glass/epoxy composites. Compos Struct 226:111308

Salleh Z, Hyie KM, Berhan MN, Taib YM, Hassan MK, Isaac DH (2013) Effect of low impact energy on kenaf composite and kenaf/fiberglass hybrid composite laminates. Paper presented at the Applied Mechanics and Materials

Sasikumar A, Trias D, Costa J, Blanco N, Orr J, Linde P (2019) Effect of ply thickness and ply level hybridization on the compression after impact strength of thin laminates. Compos Part a Appl Sci Manuf 121:232–243

Segreto T, Teti R, Lopresto V (2018) Non-destructive testing of low-velocity impacted composite material laminates through ultrasonic inspection methods. In: Characterizations of some composite materials, IntechOpen

Selver E, Potluri P, Hogg P, Soutis C (2016) Impact damage tolerance of thermoset composites reinforced with hybrid commingled yarns. Compos Part B Eng 91:522–538

Shahzad A (2019) Investigation into fatigue strength of natural/synthetic fiber-based composite materials. In: Mechanical and physical testing of biocomposites, fibre-reinforced composites and hybrid composites. Elsevier, pp 215–239

Yaghoobi H, Fereidoon A (2018) An experimental investigation and optimization on the impact strength of kenaf fiber biocomposite: application of response surface methodology. Polym Bull 75(8):3283–3309