Polym. Korea, Vol. 44, No. 5, pp. 610-617 (2020)
https://doi.org/10.7317/pk.2020.44.5.610
ISSN 0379-153X(Print)
ISSN 2234-8077(Online)

Jute/Carbon Fiber로 강화된 Epoxy-based Hybrid 복합재료의 Drop Weight Impact 및 Tension-Tension Loading Fatigue 거동

Zamurrad Arshad, Muhammad Ali Nasir, Yasir Baig*, Muhammad Zeeshan**, Rizwan Ahmed Malik***, Khubab Shaker**, Azhar Hussain***, M. Latif****, Maryam Sattar*****, and Hussein Alrobei******,†

Department of Mechanical Engineering, University of Engineering and Technology
*Beijing University of Aeronautics and Astronautics
**National Textile University
***Department of Metallurgy and Material Engineering, University of Engineering and Technology
****Department of Mechanical Engineering, Inha University
*****Department of Mechanical Engineering, Institute of Space Technology
******Department of Mechanical Engineering, College of Engineering, Prince Sattam bin Abdul aziz University

(2020년 3월 18일 접수, 2020년 4월 30일 수정, 2020년 5월 6일 채택)

Drop Weight Impact and Tension-Tension Loading Fatigue Behaviour of Jute/Carbon Fibers Reinforced Epoxy-based Hybrid Composites

Zamurrad Arshad, Muhammad Ali Nasir, Yasir Baig*, Muhammad Zeeshan, Rizwan Ahmed Malik***, Khubab Shaker**, Azhar Hussain***, M. Latif****, Maryam Sattar*****, and Hussein Alrobei******,†**

Department of Mechanical Engineering, University of Engineering and Technology, Taxila, Pakistan
**Beijing University of Aeronautics and Astronautics, No. 37 Xueyuan Road, Beijing, CN 100191*
***National Textile University, Faisalabad, Pakistan*
****Department of Metallurgy and Material Engineering, University of Engineering and Technology, Taxila, Pakistan*
*****Department of Mechanical Engineering, Inha University, Incheon, Korea*
******Department of Mechanical Engineering, Institute of Space Technology, Islamabad, Pakistan*
*******Department of Mechanical Engineering, College of Engineering, Prince Sattam bin Abdul aziz University, AlKharj, Saudi Arabia*

(Received March 18, 2020; Revised April 30, 2020; Accepted May 6, 2020)

Abstract: This work focuses on the synthesis of a novel hybrid composite, fabricated by utilizing jute and carbon fibers reinforced epoxy composites through hand layup technique to replace pure carbon-epoxy fiber composites. The mechanical properties were evaluated by drop weight impact and tension-tension fatigue tests. The tension-tension fatigue test was conducted to monitor the dynamic stiffness and fatigue life degradation of hybrid composite materials by varying the layers of jute fiber. The maximum peak load during the impact test was observed as 1081.7 N in case of carbon/jute/carbon/jute/carbon (CJCJC) stacking sequence composite materials. Finally, the surface morphology of hybrid composite materials was studied with scanning electron microscopy (SEM) after mechanical tests to check the delamination, fiber pull-out and matrix cracks. It can be concluded from the obtained mechanical results that the newly developed composite with 15% jute/carbon-epoxy hybrid materials has the potential to swap carbon-epoxy composite without much loss of fatigue life along with relatively enhanced ductility as well as impact strength.

Keywords: carbon, jute, hybrid composites, fatigue test, impact test, SEM morphology.

Introduction

During past few years, utilization of natural fibers as a reinforcement in composites has drawn much attention owing to peculiar benefits of these composite materials.[1-3] Different kinds of natural fibers have been explored including abaca, sisal, flax, coir, kenaf, jute, henequen and hemp. Natural fiber composites provide a variety of benefits over synthetic fiber composites i.e. low cost, less density with high specific strength, recyclable, biodegradable, renewable with high abrasion and thermal resistance properties. These natural fiber

†To whom correspondence should be addressed.
h.alrobei@psau.edu.sa, ORCID 0000-0002-5294-9678

composites are extensively used in aerospace, packaging, construction, sports and automotive industries.[4-6]

Among several natural fibers, jute fibers can be utilized as an alternative reinforcement in composite materials.[7] Natural fibers such as jute fiber-based composites have wider applications in automotive industries. Despite their favourable properties, natural fibers lack in thermal stability, strength and are hygroscopic in nature. Additionally, they have poor impact and fatigue strength properties.[8] Natural fibers reinforced jute fibers in polymer composites have potential to replace carbon fibers up to some extent.[9] Another possibility is that the combination of several kinds of fibers (natural and synthetic) in polymer resins can improve mechanical and physical properties, but this combination has not been satisfactorily explored so far. Such multi fiber-component composite materials comprising of a matrix phase reinforced with two different fibers with different stacking sequences are characterized as hybrid composites.[10]

In view of improving mechanical properties, the synthetic fiber reinforced composite materials can be partially replaced by relatively high strength natural fibers after hybridizing. The idea of hybridization provide flexibility to the design engineers to alter the material properties as per specific requirements, that is one of the primary advantage of composites.[11,12] The partial substitution of synthetic fibers with biodegradable natural fibers permits for the establishment of synthetic–natural hybrid composite materials, which show properties intermediate between synthetic and natural fiber composites.[13]

Among synthetic fibers, carbon fibers are most frequently used in reinforcing with both thermoplastic and thermoset resins and possessed high mechanical strength, relatively high chemical resistance and outstanding insulation properties.[14,15] Hybridization of natural fiber with synthetic fiber can enhance the mechanical and physical properties of the composite materials and thus, a stability among environmental impact and performance can be achieved at optimal cost.[16]

Based on the above-mentioned significant advantages of hybrid composites, several investigators have evaluated a range of aspects for these composite materials. Thew and Liao *et al*.[17] studied the mechanical performance of glass/bamboo fiber hybrid composite materials and concluded that the properties depends on fiber length, fiber weight ratio and interfacial adhesion among the matrix and the fiber. Velmurugan *et al*.[18] evaluated the tensile, impact, flexural strength and shear of the Palmyra/glass fiber hybrid composites. Pothan *et al*.[19] explained the impact of layering pattern of the fibers on the dynamic behaviour of banana-glass hybrid composites. A great deal of work was done by several researchers[20-23] and reported the effect of various parameters i.e. impact of fiber length and loading, fiber matrix interface and orientation of fibers on the mechanical performance of composites. Jute-fiber-reinforced polypropylene[24] with variety of chemical treatments on jute fiber was conducted to study the tensile strength. The results concluded that the most effective interfacial strength shifted to

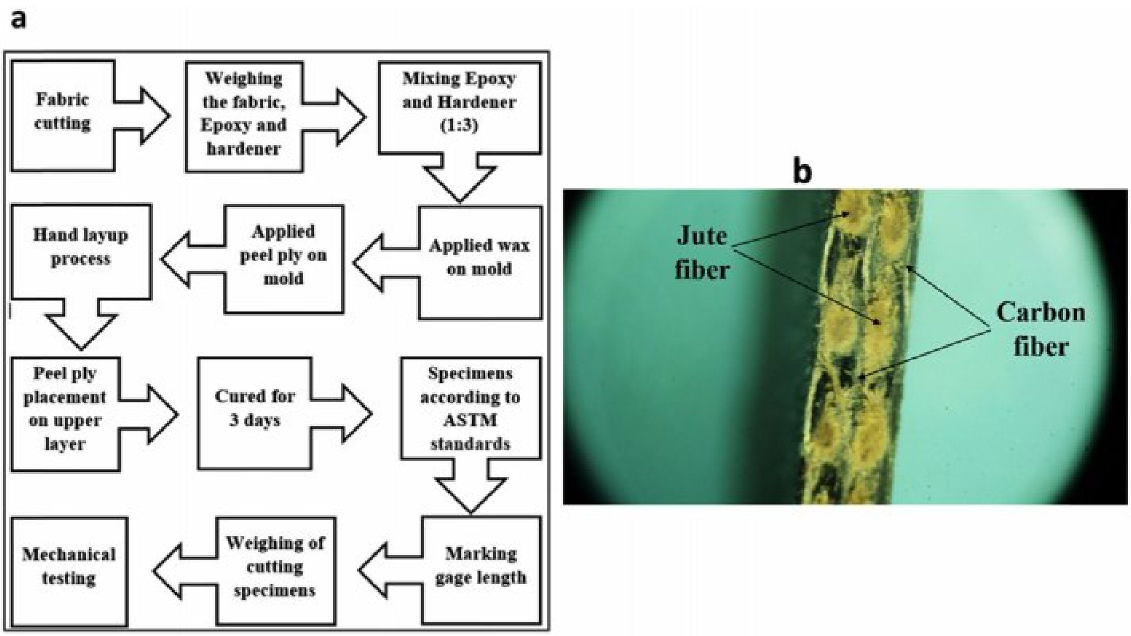

Figure 1. (a) Schematic plots of molding process for specimens; (b) stacking sequence of fibers.

low strength value based on long fiber length. Another study where kenaf / kevlar hybrid composites[25] showed higher energy absorption and low damage area as compared to pure kenaf composites as kevlar fiber prevented further destruction in composite.

In this scenario, an experiment was conducted to develop a novel hybrid polymer composite material, reinforced with eco-friendly and biodegradable jute fiber. This is developed by hybridizing carbon fiber composites with jute fiber. Mechanical properties of the developed hybrid composites were evaluated by carrying out tension-tension fatigue and impact strength tests. The tests were compared with the mechanical properties of carbon/epoxy composites and the synthetic fibers partially replaced with natural fibers in terms of hybrid composites. The SEM morphology was studied to check the damage surfaces after mechanical tests.

Experimental

Materials. Zepoxy 300 was used as an adhesive media which has two parts i.e. part A epoxy and part B hardener. The epoxy resin and corresponding hardener were mixed in the ratio of 3:1 by weight as recommended by the manufacturer. 3K plain-woven carbon fiber having 0.2 mm thickness and plain-woven jute fabric of 0.8 mm thickness was used.

Preparation of Hybrid Composites. Hand layup technique was used for the manufacturing of hybrid composites. The schematic plots of molding process for specimens and fibers diverse stacking sequence were shown in Figure 1. First of all, the mold surface was treated by releasing agent to avoid the sticking of polymer to the surface. Then, a thin peel ply sheet was applied on the surface of the mold to achieve good surface finish.

The desired stacking sequences of carbon/carbon/carbon/carbon/carbon (C5), carbon/carbon/jute/carbon/carbon (CCJCC), carbon/jute/carbon/jute/carbon (CJCJC) and carbon/jute/jute/jute/carbon (CJJJC) fibers were placed manually in mold. By utilizing a brush, the epoxy resin was applied on the fibers. Later, hand rollers were utilized for rolling the wet composite material to make sure an improved interaction among the reinforcement and resin, to assist a homogeneous resin distribution, and to acquire the needed thickness of the final product.

Mechanical Testing of Composites. The main intention of this study is to make a comparison of the properties of pure carbon-epoxy composites with jute/carbon-epoxy hybrid composites by varying the layers of jute fiber for establishing the newly optimized hybrid composite which can replace pure carbon-epoxy composites.

Fatigue Test. Fatigue testing was performed by utilization

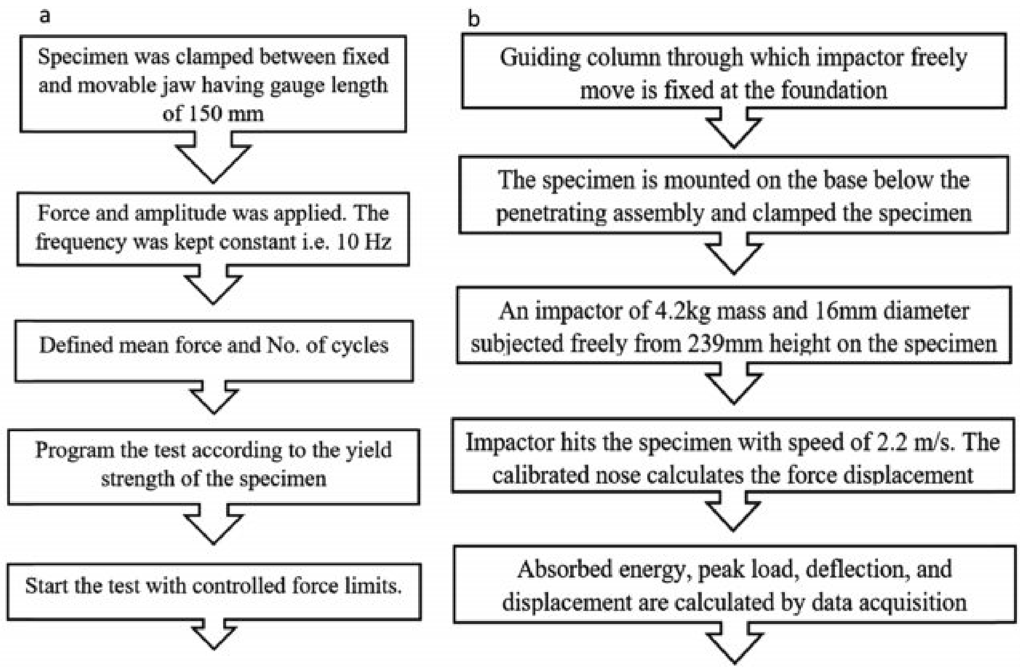

Figure 2. (a) Schematic representation of fatigue test performed on Zwick/Roell Z100 machine; (b) schematic representation of drop weight impact testing.

Table 1. Parameters Obtained from Low-velocity Drop Weight Impact Test on Carbon/Jute Hybrid Composites

Specimens designation	Impacted energy E_i (J)	Absorbed energy E_a (J)	Peak load (N)	Energy to peak load (J)	Maximum deflection (mm)	Damage area (mm²)	Ductility index	Damage degree
CCJCC	10	8.72	966.88	6.36	6.34	286.5	0.371	0.87
CJCJC	10	8.65	1081.7	6.35	7.77	216.1	0.3622	0.87
CJJJC	10	8.89	841.1	7.12	6.66	710.6	0.23	0.89

of Zwick/Roell Z100 according to ASTM D3039 standards, schematically shown in Figure 2(a). Fatigue test was done on samples having dimensions of 250 mm×25 mm. The test was done with 55%, 65% and 75% of ultimate tensile load of samples that were applied under monotonic load. The stress ratio and loading frequency was R=0.1 (minimum load/maximum load) and 10 Hz respectively.

Drop Weight Impact Test. Drop weight impact testing was done by utilizing Zwick/Roell HIT230F machine, schematically shown in Figure 2(b). In a drop weight impact test, the impactor contacts the specimen's surface only for a few milliseconds. During this small period of time, histories of the absorbed energy, peak load, deflection, energy to peak load and displacement were calculated by data acquisition system as depicted in Table 1. All samples were tested at low impact velocity of 2.2 m/s and fixed energy of 10 Joules with impactor of mass 4.2 kg having 16 mm diameter.

Results and Discussion

Fatigue Test. Generally, the fatigue failure in composites showed three phases. The first phase is usually the consequence of gradual degradation with slightly change in its rate till 20% N_f which is mainly due to single matrix crack. The second phase is related to the stiffness of the composites which normally remains stable throughout the phase. However, the third phase is related to the catastrophic failure of the composites due to the propagation of a single matrix crack until it reaches a certain level.[26] The lamina properties have been taken from a reference cited at.[27] Numerous fatigue test studies concentrated on enhancing the interface strength of the fiber/matrix to effectively prevent crack beginning in composites and its diffusion under fatigue loading.

The fatigue behaviour of tested samples up to their failure cycles were shown in Figure 3. From the S-N curves figure, the fatigue strength progressively decreased with the increasing fatigue cycle numbers. Pure carbon/epoxy composites showed higher fatigue strength as compared to its hybridization with jute. The fatigue strength of carbon/epoxy composites was also investigated by Cole *et al*.[28]

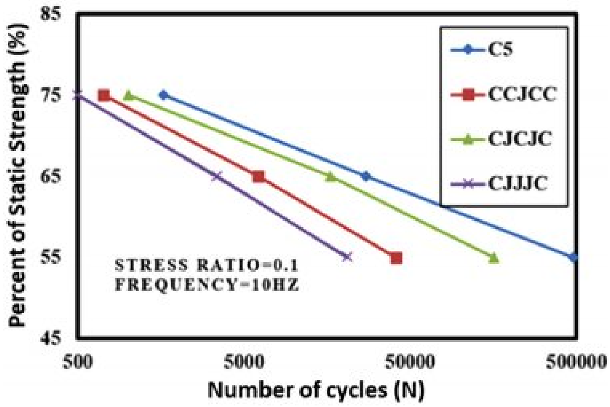

Figure 3. S-N curves at different loading condition in log linear cycles (N).

Hybrid composites fatigue life decreased with increasing jute fiber layers as shown in Figure 3. The low modulus jute fiber has maximum elongation which after hybridization with carbon fiber, will increased the overall elongation of hybrid composite but has adverse effect on fatigue life. The CCJCC hybrid composites showed slightly less fatigue strength as compared to carbon/epoxy composites (C5). The lowest fatigue strength was noted in hybrid composites with three layers of jute fibers (CJJJC) may be due to the weak interfacial adhesion between dissimilar fibers as shown in SEM graphs. Hence, at higher number of fatigue cycles, jute fiber represented higher degradation as compared to carbon. The same results was also obtained by Padmaraj in his research.[29]

The trend in stiffness degradation was observed to estimate the crack progression under cyclic loading.[30] Fatigue damage in composite materials always decreases the stiffness as opposed to composite strength. The trend of stiffness versus number of cycles to failures for all studied stacking sequences were shown in Figure 4. For 60% and 65% of UTS stiffness degradation of C5 and carbon/jute hybrid composites were evaluated respectively. During the initial cycles in all four stacking sequence cases, the stiffness degradation decreased at a high rate. At imposed load level, fatigue failures of hybrid composites seemed to be quite sensitive. C5 showed the max-

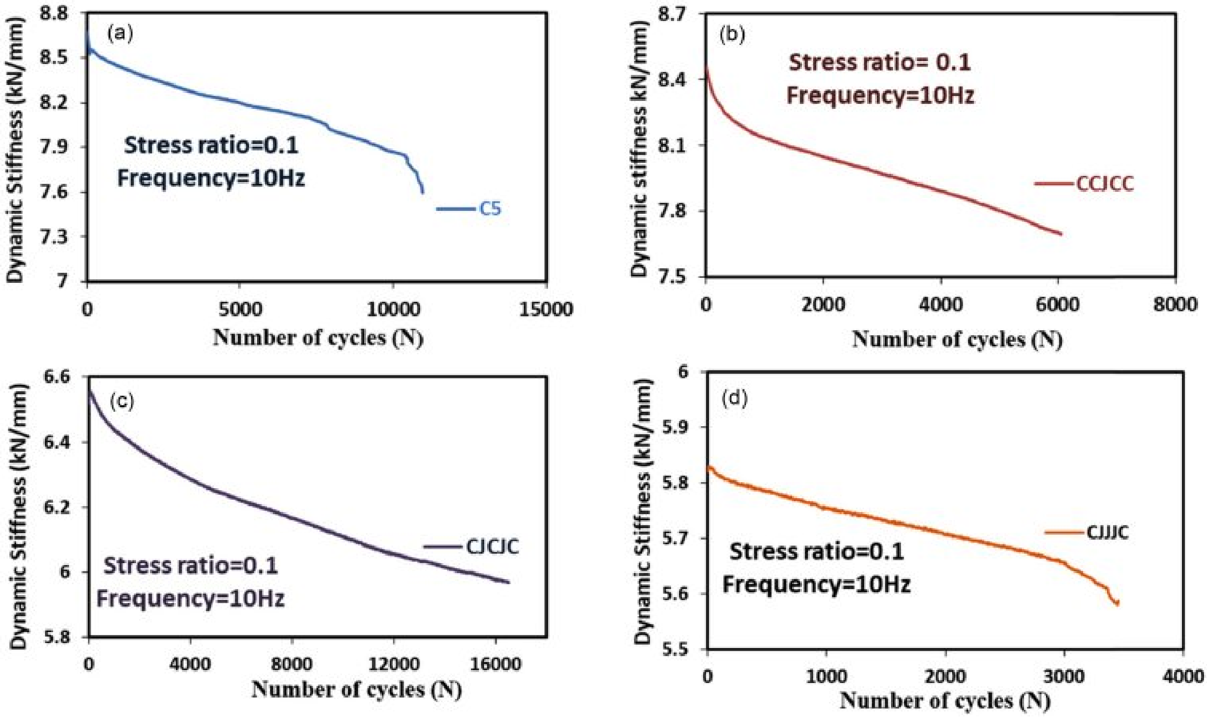

Figure 4. Stiffness degradation *vs* number of cycles to failures: (a) C5; (b) CCJCC; (c) CJCJC; (d) CJJJC.

imum rate of degradation, while CJJJC had the lowest rate of degradation. For all four combinations at 5.6 kN/mm and above, a minute and sudden stiffness degradation curve was observed that investigated the damage growth.

The fracture region of the carbon fiber under cyclic loading reveals that transverse crack transmitting inside a yarn and diffused into the nearest yarns rising to a flat crack region as shown in Figure 5(a). This transverse fracture has transmitted perpendicular to the directions of fibers, traveling to the next fibers, and ultimately, creating an almost flat crack.

The SEM micrographs revealed that damage happened only in the matrix region, especially at the region where matrix is rich as shown in Figure 5(b). Figure 5(c) and 5(d) depicts the failure region of the carbon/jute hybrid composites because of tension-tension loading. Jute fibers pull-out behaviour can be seen in the SEM images due to weak interfacial bonding between fibers and matrix.

Drop Weight Impact Test. Impact energy is referred to as the kinetic energy of the system before an impactor hits the specimen. However, after an impact occurs, the absorbed energy becomes the dissipated energy which is given off by the system under consideration. After hitting the impactor with specimen, several mechanisms occur, like plastic and elastic deformation, cracks in the matrix, fibers pull-out and friction.

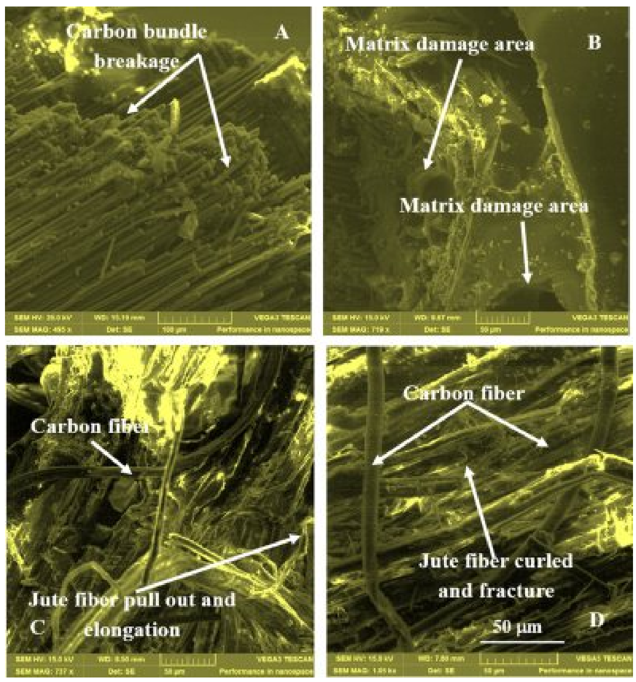

Figure 5. (a) SEM images of the CFRPs fractured under fatigue loading; (b) epoxy cracks after fatigue loading; (c) and (d) jute fiber pull-out and fiber breakage.

In case of impact test, matrix cracking and delamination are the leading causes of failure. The calculated damaged area

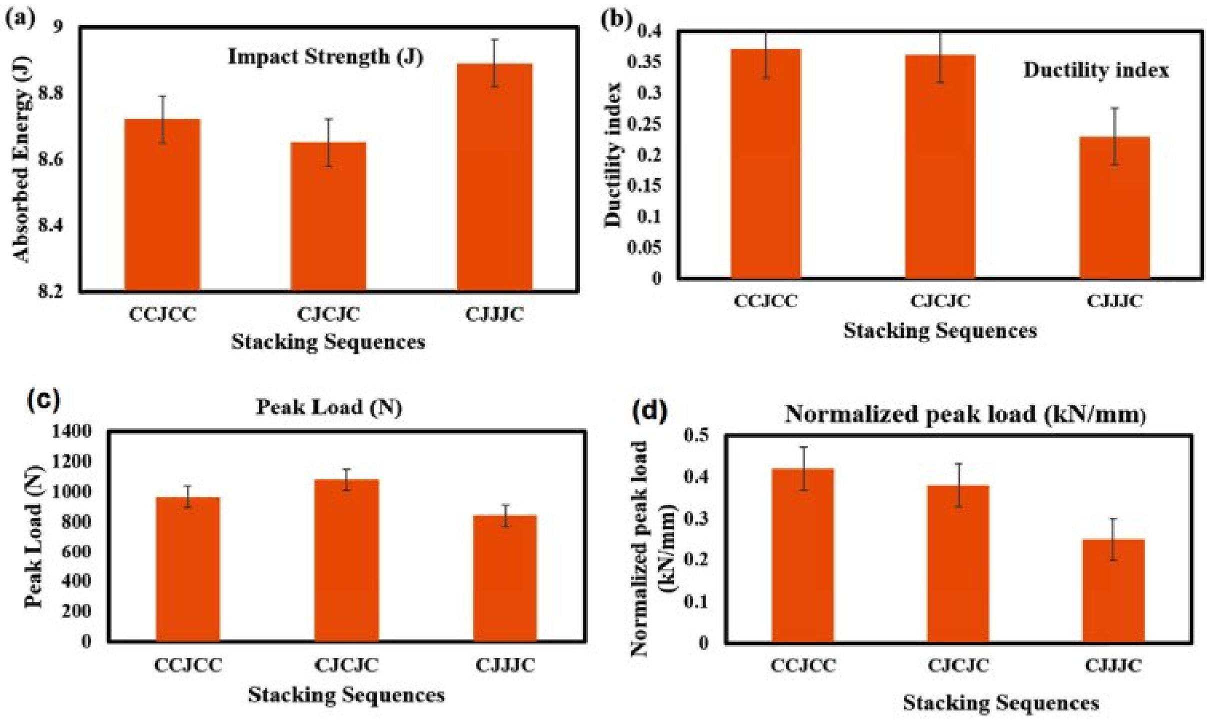

Figure 6. (a) Absorbed energy of laminates; (b) ductility index of laminates; (c) effect of pure carbon and its hybrids with jute on peak load at the same impact; (d) effect of pure carbon and its laminates with jute using notion of normalization.

after test along with other parameter information of hybrid composites was shown in Table 1. While analysing the damage area response of hybrid laminates, it can be noticed that CJJJC reveals the maximum damaged area or high deformation. These types of hybrid composites are responsible for more energy absorption as compared to others. Hybrid composites specially CJJJC showed the broadest damaged regions because of the enhanced amount of events befall at the various interfaces between the layers of jute and carbon fiber as explained in the other work.[31] By increasing jute fiber mass percentage in hybrid composites, the damage degree ratio increased as shown in Table 1. This revealed the encouraging effect of hybridizing jute fiber with carbon fiber, which improved the total energy E_a.

In Figure 6(a), the energy absorbed by laminates showed that the energy absorption increased by increasing percentage of jute layers in hybrid composites. M. V. Ramana[32] also reported in his study that jute/epoxy showed higher impact strength as compared to pure carbon fiber composites.

Ductility index (DI) is another way to find impact strength of composites as shown in Figure 6(b). CJJJC showed lowest ductility index among all the stacking sequences, which indicated that hybrid composite with maximum percentage of jute fiber are brittle as compared to other hybrid composites. Due to low DI, these composites required a huge amount of energy to initiate damage. However, after the damage occurred, a little addition of energy will deteriorate the composites completely. High DI indicated that no catastrophic failure occurred because these composites can withstand more load just after damage.

The response of peak loads under constant energy for all investigated samples were shown in Figure 6(c) which indicated the stiffness of hybrid composites. The CJCJC and CCJCC showed the maximum peak load, so these two hybrid composites were stiffer than others. These stiffer composites collapse less and absorb more load as compared to others.

The thickness of samples also effects the rate of energy absorption and peak load of composites. For this, the notion of normalization was used in Figure 6(d). The tremendous difference can be observed between the actual peak load and the normalized peak load. These three parameters (ductility index, peak load and normalized peak load) were also reported in the study of M. T. Isa[33] for different hybrid composites.

Fractography was performed on Olympus optical microscope (BX51) to study failure mode of CJCJC stacking sequence hybrid composites after drop weight test. Images of fractured specimens were taken from different regions of spec-

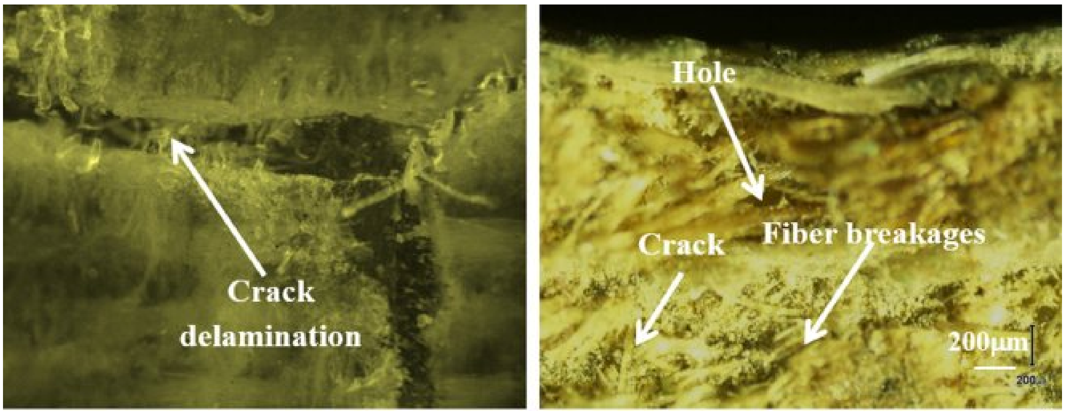

Figure 7. Damage pattern of samples under drop weight impact test.

imens as shown in Figure 7. From the figure, a crack delamination phenomenon can be seen due to weak interfacial bonding among fibers and matrix. Figure 7 also revealed the matrix cracking and fiber breakage behaviour in hybrid composites. It can be noticed that the matrix cracking always promote the delamination between the plies.

Conclusions

Carbon/jute hybrid composites were designed to investigate their fatigue life, impact strength and morphological properties. The carbon/epoxy composites yielded highest fatigue strength due to greater stiffness of carbon fiber but with the increase in jute fiber layers, the fatigue strength decreases. In low velocity drop weight impact test, CCJCC and CJCJC hybrid composites prevented the crack penetration but enhanced the peak loads as compared to other laminates. Absorbed energy, damage degree and ductility index are improved by increasing percentage of jute fiber. The maximum peak load during impact test was observed as 1081.7 N in case of carbon/jute/carbon/jute/carbon (CJCJC) stacking sequence hybrid composites. Further, the SEM revealed that fatigue life of hybrid composites decreased due to elongation and pull-out effect of jute fibers. Fractographic of drop weight impact test samples revealed that increasing percentage of jute fibers will increase damage area. Hence, this hybridization of carbon/jute composites especially CJCJC stacking sequence was suggested as the best economical and productive combination.

Acknowledgment: This publication was supported by the Deanship of Scientific Research at Prince Sattam bin Abdul aziz University, Alkharj, Saudi Arabia.

References

1. H. N. Dhakal, Z. Y. Zhang, R. Guthrie, J. MacMullen, and N. Bennett, *Carbohydr. Polym.*, **96**, 1 (2013).
2. R. Vijayan and A. Krishnamoorthy, *Mater. Today Proc.*, **16**, 897 (2019).
3. M. Latif, M. N. Prabhakar, G. B. Nam, D. W. Lee, and J. I. Song, *Compos. Res.*, **30**, 303 (2017).
4. A. K. Gholampour and T. Ozbakkaloglu, *J. Mater. Sci*., **55**, 829 (2020).
5. R. Sana, K. Foued, B. M. Yosser, J. Mounir, M. Slah, and D. Bernard, *Fiber Polym.*, **16**, 2451 (2015).
6. H. U. Zaman and M. D. H. Beg, *Fiber Polym.*, **15**, 831 (2014).
7. K. Jha, B. B. Samantaray, and P. Tamrakar, *Mater. Today Proc.*, **5**, 5601 (2019).
8. H. Singh, J. P. Singh, S. Singh, V. Dhawan, and S. K. Tiwari, *Mater. Today Proc.*, **5**, 28427 (2018).
9. M. Ahsan, M. Zwawi, M. Taqi, R. Kanthasamy, and A. Bahadar, *Fibers*, **7**, 77 (2019).
10. H. P. S. A. Khalil and C. W. Kang, *J. Reinf. Plast. Compos.*, **28**, 1123 (2009).
11. R. A. Braga and P. A. A. Magalhaes, *Mater. Sci. Eng., C*, **56**, 269 (2015)
12. C. Santulli, M. Janssen, and G. Jeronimidis, *J. Mater. Sci.*, **40**, 3581 (2005).
13. M. Shamsuyeva, J. Winkelmann, and H. J. Endres, *J. Compos. Sci.*, **3**, 43 (2019).
14. M. Latif, M. N. Prabahakr, and J. Song, *J. Appl. Polym. Sci.*, **136**, 47695 (2019).
15. M. Latif, C. N. Kumar, M. N. Prabahakr, and J. Song, *Fiber Polym.*, **20**, 413 (2019).
16. M. R. Sanjay, G. R. Arpitha, and B. Yogesha, *Mater. Today Proc.*, **2**, 2959 (2015).
17. M. M. Thwe and K. Liao, *J. Mater. Sci. Lett.*, **19**, 1873 (2000).
18. R. Velmurugan and V. Manikandan, *Compos. Part A - Appl. Sci. Manuf.*, **38**, 2216 (2007).
19. L. A. Pothan, C. N. George, M. J. John, and S. Thomas, *J. Reinf.*

Plast. Compos., **29**, 1131 (2010).
20. F. Basiji, V. Safdari, A. Nourbaksh, and S. Pilla, *Turk. J. Agric. For.*, **34**, 191 (2010).
21. V. Vilay, M. Mariatti, R. M. Taib, and M. Todo, *Compos. Sci. Technol.*, **68**, 631 (2008).
22. H. Alamri and I. M. Low, *Polym. Test.*, **3**, 620 (2012).
23. G. Goud and R. N. Rao, *Bull. Mater. Sci.*, **35**, 595 (2012).
24. K. Shima, K. Okubo, and T. Fujii, *WIT Trans. Eng. Sci.*, **39**, 261 (2003).
25. N. H. Bakar, K. M. Hyie, C. M. Mardziah, N. R. N. Roselina, and N. R. N. Masdek, *J. Teknol.*, **76**, 25 (2015).
26. R. Tang, Y. J. Guo, and Y. J. Weitsman*, Int. J. Fatigue*, **26**, 421 (2004).
27. A. Ali, M. A. Nasir, M. Y. Khalid, S. Nauman, K. Shaker, S. Khushnood, K. Altaf, M. Zeeshan, and A. Hussain, *J. Mech. Sci. Technol.*, **33**, 4217 (2019).
28. D. P. Cole, T. C. Henry, F. Gardea, and R. A. Haynes, *Compos. Sci. Technol.,* **151**, 202 (2017).
29. N. H. Padmaraj, K. N. Chethan, Pavan, and A. Onkar*, IOP Conference Series: Mater. Sci. Eng.*, **225**, 012017 (2017).
30. S. D. Salman, M. J. Sharba, Z. Leman, M. T. H. Sultan, M. R. Ishak, and F. Cardona, *BioResources*, **11**, 3575 (2016).
31. F. Sarasini J. Tirillo, L. Ferrante, M. Valente, T. Valente, L. Lampani, P. Gaudenzi, S. Cioffi, S. Iannace, and L. Sorrentino, *Compos. Part B-Eng*., **59**, 204 (2014).
32. M. V. Ramana and S. Ramprasad, *Mater. Today Proc.*, **4**, 8654 (2017).
33. M. Isa, A. Ahmed, B. Aderemi, R. M. Taib, H. M. Akil, and I. A. M. Dabo, *Leonardo EI. J. Pract. Technol.,* **13**, 97 (2014).