Tensile and flexural properties of woven carbon-kenaf fiber reinforced epoxy matrix hybrid composite: Effect of hybridization and stacking sequences

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Tensile and Flexural Properties of Woven Carbon-Kenaf Fiber Reinforced Epoxy Matrix Hybrid Composite: Effect of Hybridization and Stacking Sequences

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Abstract. Hybrid composites from combinations of synthetic and natural fibers have experienced a considerable interest among researchers due to its excellent characteristics. One of the drivers for this development owing to the ability of synthetic and natural fibers to compensate for the limitation of one another. Thus, the current effort works on the fabrication of hybrid composites from combinations of carbon fiber (C) and kenaf fiber (K) with epoxy resin using the vacuum infusion method. The stacking sequences of fibers were varied to KKKKK, CKCKC, KCKCK, and CCKCC. The effects of hybridization and stacking sequences on mechanical properties of fabricated hybrid composites were examined under tensile and flexural tests. The result shows that the tensile and flexural properties of manufactured hybrid composites were enhanced by introducing hybridization with carbon fiber. The highest tensile were obtained in the CKCKC hybrid sample, whereas, the highest flexural properties were observed in the CCKCC hybrid sample. Besides, tensile fractured and flexural modes of failures were characterized using a scanning electron microscope (SEM) and optical microscope (OM), respectively.

1. INTRODUCTION

Composite materials from natural fibers become the subject of interest in many studies. Natural fibers such as kenaf, hemp, jute, sisal, and bamboo commonly embedded with a polymer matrix to form composite materials [1,2]. The selection of these natural resources due to advantages offered by them including renewable resources, excellent biodegradable properties, low density, and abundantly available [3,4]. In many decades, composites from natural fibers broadly adopted in non-structural applications such as rope, bags, twines, and become an alternative for wood-based products [1]. Interestingly, researchers start to explore the potential of natural fibers for structural uses especially in construction and automotive components. However, the mechanical properties of composites from natural fibers are lower than synthetic composites [5,6]. Another obstacle in developing this composite is a high moisture absorption of natural fibers that consequently downgrade its mechanical performances in certain environmental conditions has limited the usage of these resources for long-term use [7].

Realizations about these problems, researchers have come out with several solutions to improve the mechanical aspects of natural-based composites. One of the best approaches is through the hybridization technique with synthetic fibers. Hybridization refers to a technique employed by introducing two different types of fibers into a composite system to form a hybrid composite [8]. The combination of natural fibers with synthetic fibers tends to compensate

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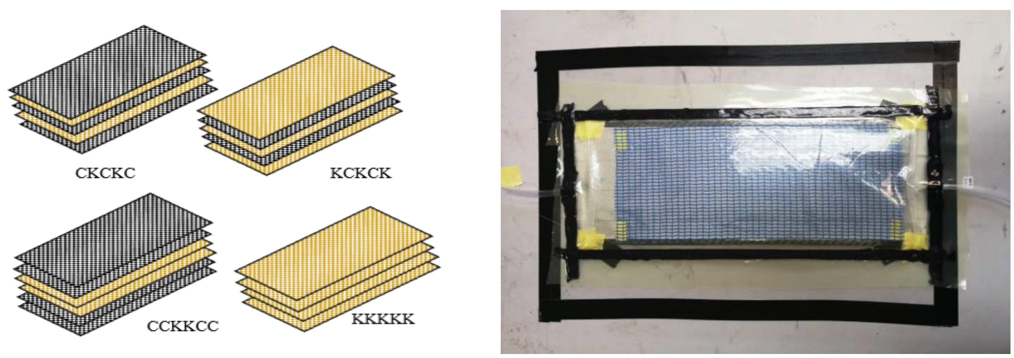
for the limitation of natural resources, thus, it will improve the mechanical performances [9]. Many attempts have been conducted from previous studies that investigate the effects of hybridization of kenaf fiber with glass fiber on mechanical properties of kenaf hybrid composites based on several parameters such as fiber-to-matrix ratio, fiber orientation, and weave pattern [10]. However, only little interest was performed that identify the effect of hybridization and stacking sequences on the mechanical properties of carbon-kenaf hybrid composites. Therefore, kenaf and carbon fibers were used in the current project in which epoxy resin was utilized to bind and hold these fibers. The effect of hybridization on kenaf hybrid composite with carbon fiber was evaluated. Moreover, this study also aims to investigate the effect of fibers' stacking arrangements on mechanical behaviors of kenaf hybrid composites that fabricated using vacuum infusion method.

2. MATERIALS AND METHOD

Carbon-kenaf hybrid composites were fabricated by having a 40 vol.% of fiber loading, 3 mm thickness, and the stacking configurations of KKKKK, CKCKC, CCKCC, and KCKCK as shown in Figure 1 (a). The ratio of carbon-to-kenaf fixed at 1:1. Kenaf and carbon fibers in a from woven (0°/90° fiber orientation) were prepared with a dimension of 300 mm × 200 mm. Epoxy resin together with hardener (INF-212) was used as a matrix constituent in which the ratio of epoxy-to-hardener remained at 100:24.9. A vacuum infusion method was employed to manufacture carbon-kenaf hybrid composites wherein the setup of this technique shown in Figure 1 (b). The fabrication involves the use of pressure from the vacuum pump. A constant pressure (-100 kPa) was supplied from a vacuum pump to infuse the epoxy resin along the surface of fibers. The composite panel underwent a curing process for 24 hours at room temperature to obtain solid hybrid composite panels.



(a) (b)

FIGURE 1. Schematic diagram of various stacking configurations and (b) vacuum infusion setup

Tensile and flexural tests were performed in order to evaluate the mechanical performances of manufactured hybrid composites. Five specimens were prepared for both mechanical testing. For tensile test, the sample was cut into a dimension of 250mm × 25mm × 3mm according to the ASTM D3039 standard. The Universal Testing Machine (INSTRON 5582) with a crosshead speed of 2 mm/min and 100 kN load were used to identify the tensile properties of carbon-kenaf hybrid composites. The same machine was used to perform a three-point bending test. Five replicates were prepared by having a dimension of 127mm × 13mm × 3mm based on the ASTM D970 standard. Tensile fractured failures were observed using scanning electron microscope (SEM, model JOEL JSM-5600) in which Palladium (Pd) was used as a coating element to reveal the microstructure of hybrid composites performed using Quarom SC7620 Sputter Coater at 10 Kv voltage. Flexural modes of failures were identified using Nikon Measuring Microscope Trinocular Head, model MM-TRF.

3. RESULTS AND DISCUSSION

3.1. Tensile Properties of Carbon-Kenaf Hybrid Composites

Figure 2 (a) shows the tensile strength of fabricated hybrid composites at four different stacking sequences. The KKKKK sample was fabricated as a reference in which the tensile strength of this composite was found at 79.68 MPa. The highest tensile strength was attained at 210.49 MPa belongs to CKCKC stacking sequence. Based on this value, tensile strength has improved by 62.15% compared to a pure kenaf composite. Meanwhile, for KCKCK stacking sequence the tensile strength has increased by 40.82% than KKKKK composite in which the value of tensile strength gained at 134.65 MPa. The same trend can be observed in CCKCC composite in which the tensile strength achieved at 202.77 MPa that is 60.70% higher than the KKKKK composite. The tensile modulus of carbon-kenaf hybrid composites is presented in Figure 2 (b). A similar pattern as tensile strength can be observed for tensile modulus. Based on Figure 2 (b), the value of tensile modulus for reference KKKKK sample recorded at 2.21 GPa. The tensile moduli of hybrid composites have increased by more than 70% in comparison to the control sample. More specifically, the tensile modulus of CKCKC, KCKCK, and CCKCC hybrid composite obtained at 10.60 GPa, 7.95 GPa, and 10.48 GPa, respectively.

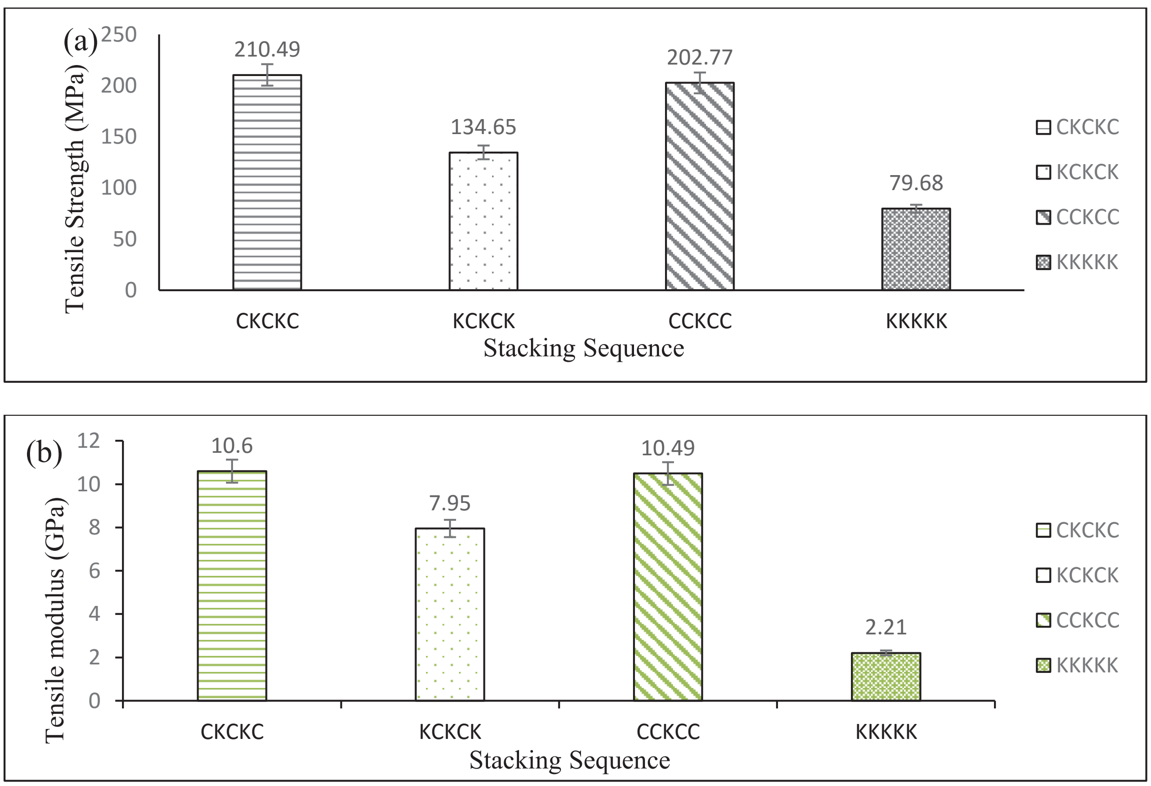


FIGURE 2. (a) Tensile strength and (b) tensile modulus of hybrid composites at various stacking sequences

High tensile performances of hybrid composites due to the addition of carbon fiber. In fact, carbon fiber exhibits excellent mechanical behaviours that consequently able to withstand longer under a tension condition in contrast to kenaf fiber [11]. A similar finding was recorded from the previous study in which hybridization of sisal composites with glass fibers significantly improve the tensile strength (168.63 MPa) and modulus (0.7216 GPa) of a hybrid composite as compared to tensile strength (31.85 MPa) and modulus (0.2219 GPa) of neat sisal composite [12]. The highest tensile properties were found in the CKCKC hybrid composite. Excellent tensile properties of CKCKC sample due to the effectiveness of interfacial bonding between carbon-kenaf fibers and epoxy matrix to resist the tension load.

As confirmed by SEM morphology, based on Figure 3 (a) good laminations were observed in the CKCKC hybrid that indicates matrix resin able to play its role to bind the fibers completely. The formation of good laminations in this hybrid composite due to the effectiveness of matrix resin to evenly distribute across the fiber surfaces in the composite system [9]. Besides, a severe fiber pull-out phenomenon can be observed in the middle of CCKCC hybrid composite as shown in Figure 3 (b). The appearance of this failure due to the lower strength of kenaf fibers to resist applied forces. Meanwhile, severe delamination defects can be detected in the KCKCK sample as shown in Figure 3 (c). This failure can be clearly seen by observing the appearance of gaps between layers of fibers. Epoxy resin unable to laminate the fibers effectively that consequently promote poor fiber-matrix interfacial bonding. It is due to the assignation of natural fiber as the outer skin which increases the tendency to absorb more resin and therefore disrupt the flow of matrix in the core layer of the composite [2]. As a result, when a certain degree of tension loads was applied fibers unable to stand as a load receiver efficiently. This finding becomes evidence of poor tensile properties of KCKCK and CCKCC hybrid samples as compared to the CKCKC hybrid sample. As expected, from Figure 3 (d), KKKKK control sample experiencing severe fiber pull-out failures due to low strength of kenaf fiber that unable to withstand longer in the tension condition, thus, lead to poor tensile behaviours of kenaf composite.

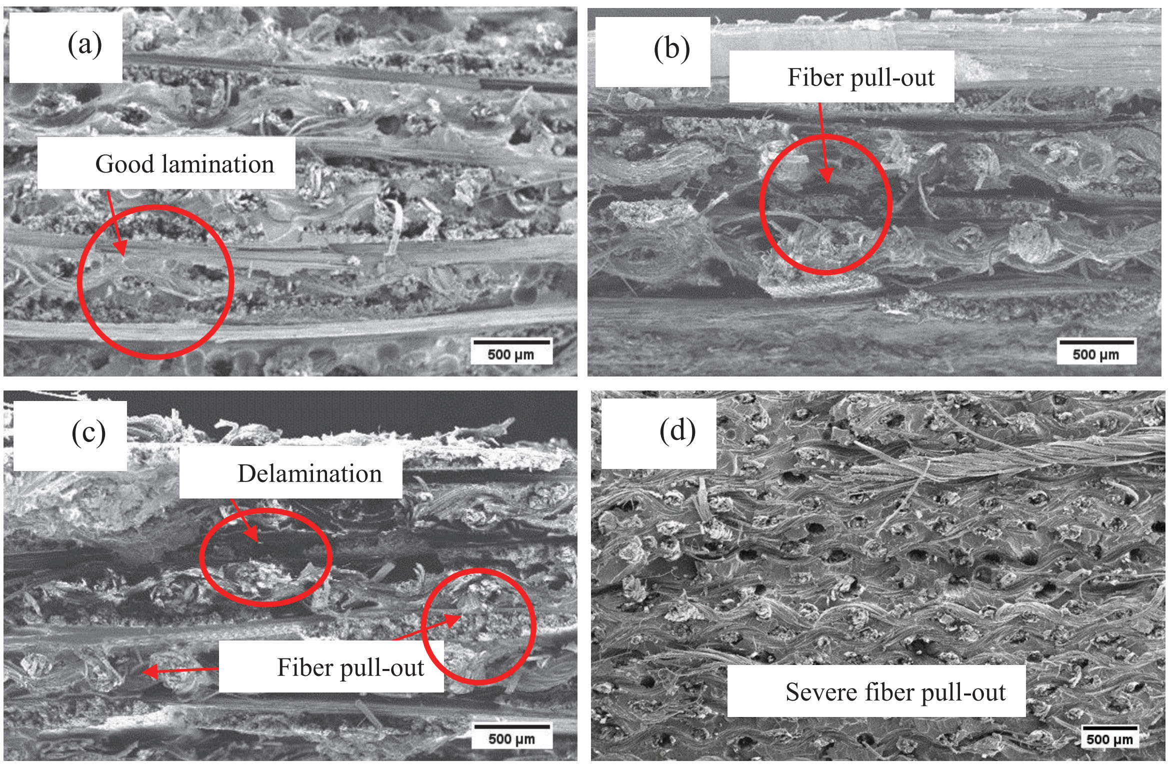


FIGURE 3. Tensile fractured of (a) CKCKC, (b) CCKCC, (c) KCKCK, and (d) KKKKK at ×35 magnification

3.2. Flexural Properties of Carbon-Kenaf Hybrid Composites

Figure 4 (a) displays the flexural strength of carbon-kenaf hybrid composites. It should note that the flexural strength of fabricated hybrid composites is higher than a reference kenaf composite. The highest flexural strength was observed at 299.31 MPa when CCKCC pattern was applied as a stacking sequence of fibers. Meanwhile, the CKCKC sequence exhibits a comparable flexural strength as CCKCC composite in which the value was gained at 221.70 MPa. Whereas, the KCKCK hybrid composite shows the lowest flexural strength compared to CKCKC and CCKCC samples. A high value of flexural strength in CKCKC and CCKCC sequences due to good bending stress endurance when carbon fibers were attached as outer layers in a hybrid composite system as compared to kenaf fiber as an outer layer. The outer layer carbon fibers were able to compensate for the limitation of weak kenaf fibers that consequently result in good flexural strength.

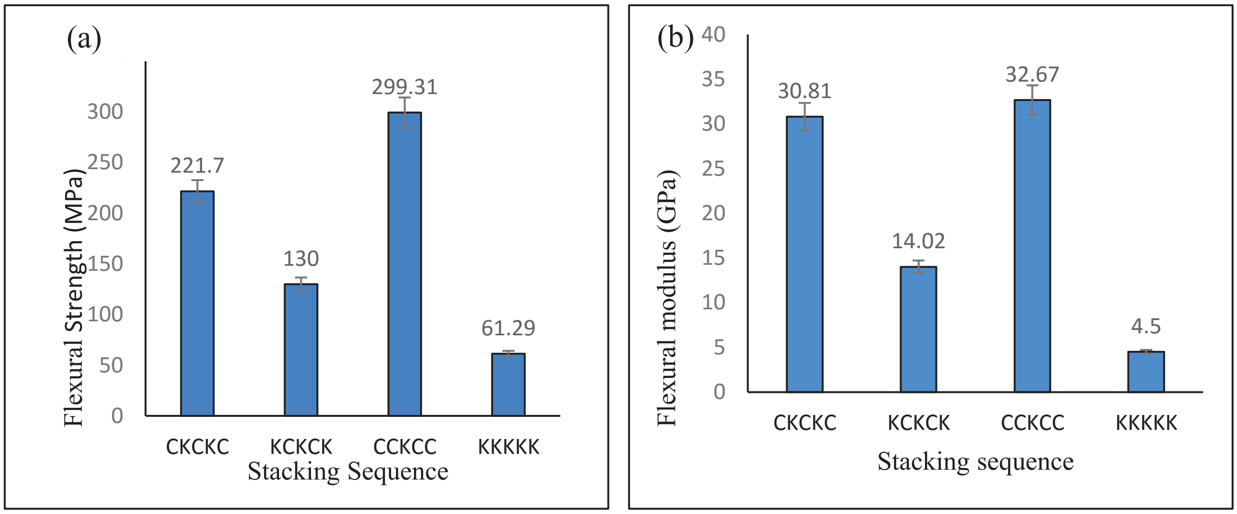


FIGURE 4. (a) Flexural strength and (b) flexural modulus of carbon-kenaf hybrid composites at various stacking sequences

A significant difference in flexural modulus between fabricated hybrid composites and KKKKK composite can be observed as shown in Figure 4 (b). The highest flexural modulus was obtained at 32.67 GPa belongs to the composite sample with CCKCC stacking sequence. Flexural modulus of CCKCC hybrid composite has improved by 86.23% as compared to KKKK composite sample. The same goes for the CKCKC hybrid composite in which a huge improvement in flexural modulus can be detected. In terms of percentage, the flexural modulus of this composite has increased by 85.39% compared to the KKKKK sample wherein this value was attained at 30.81 GPa. Amongst the fabricated hybrid composites, the sample with sequence KCKCK exhibits the lowest flexural modulus where the value was gained at 14.02 GPa. It indicates that kenaf fibers unable to play its role as a load receiver by giving sufficient protection when a certain level of loads was applied on a composite system. However, the flexural modulus of this pattern has enhanced by 67.90% as compared to pure kenaf composite.

Based on optical micrographs shown in Figure 5, flexural failure starts to initiate at the bottom part of the samples. Then this failure continues to propagate before experiencing permanent damage under bending stress. Based on Figure 5 (a) (b), it can be observed that crack only propagates at the bottom part of CKCKC and CCKCC hybrid samples. It is because of the high strength of carbon fiber able to provide enough support as a load barrier to resist the bending stress. Thus, a drastic propagation of crack can be prevented that result in better flexural properties in CKCKC and CCKCC hybrid composites as compared to KCKCK and control samples. Large crack propagation can be observed in samples KCKCK and KKKKK as shown in Figure 5 (c) and Figure 5 (d), respectively. The outer layer of kenaf fibers unable to withstand longer in a bending load that contributes to major damage due to the rapid state of crack propagations. Meanwhile, Figure 5 (g-h) represents the surface of sample CKCKC, CCKCC, KCKCK, and KKKKK, respectively. It can be depicted that good lamination between fiber and resin was observed in CKCKC and CCKCC hybrid composites. Whereas, the appearance of voids can be seen in the KCKCK and KKKKK samples. It indicates that the assignation of kenaf fiber as an outer layer tends to promote more voids due to the high rate of resin absorption that negatively influenced the flexural properties of fabricated composite materials [2].

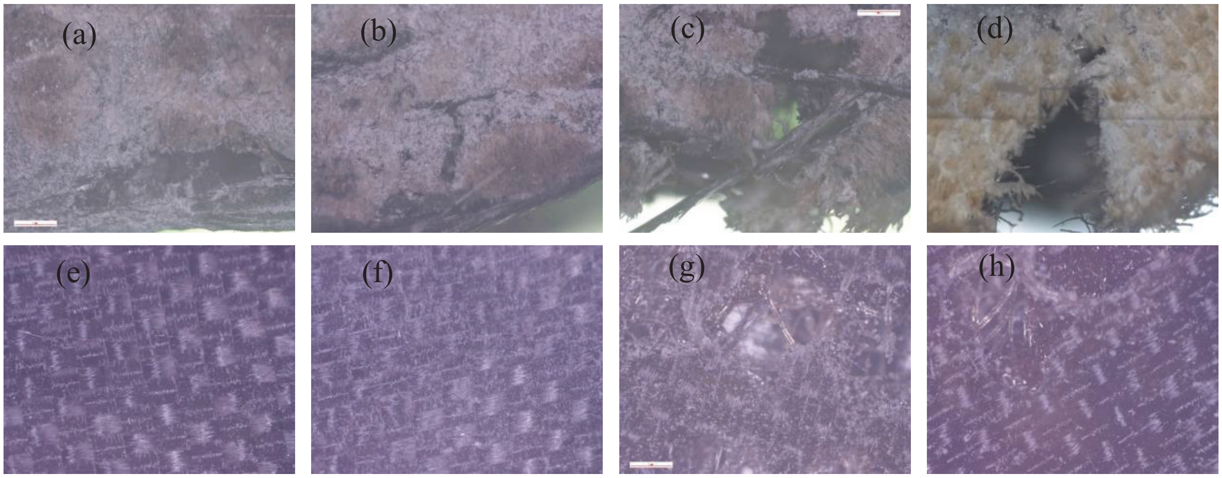


FIGURE 5. Flexural mode failures of (a) CKCKC hybrid sample, (b) CCKCC hybrid sample, (c) KCKCK hybrid sample, (c) KKKK control sample and surface morphology of (e) CKCKC hybrid sample, (f) CCKCC hybrid sample, (g) KCKCK hybrid sample, and (h) KKKKK control sample

4. CONCLUSIONS

The effect of hybridization as well as stacking sequences on tensile and flexural properties of carbon-kenaf hybrid composite were studied. From this research, it can be concluded that:

1) Hybridization of kenaf composite with carbon fiber has successfully improved the mechanical performances of fabricated composite materials
2) Hybrid composite with the CKCKC stacking sequence exhibits outstanding tensile properties compared to other fibers' stacking sequences.
3) Amongst the fabricated hybrid composites, the highest flexural behaviours can be observed in the CCKCC hybrid composite.
4) The assignation of carbon fibers as the outer layers resulted in excellent tensile and flexural properties as compared to kenaf fibers as an outer surface.

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REFERENCES

1. Väisänen, T., Das, O., & Tomppo, L. A review on new bio-based constituents for natural fiber-polymer composites. *Journal of Cleaner Production*, 2017, 149, 582–596.
2. Elanchezhian, C., Ramnath, B. V., Ramakrishnan, G., Rajendrakumar, M., Naveenkumar, V., & Saravanakumar, M. K. Review on mechanical properties of natural fiber composites. *Materials Today: Proceedings*, 2018, 5(1), 1785–1790.

3. Arpitha, G. R., & Yogesha, B. An Overview on Mechanical Property Evaluation of Natural Fiber Reinforced Polymers. *Materials Today: Proceedings*, 2017, 4(2), 2755–2760.
4. Ranakoti, L., Pokhriyal, M., & Kumar, A. Natural Fiber and Biopolymer Characterization: A Future Potential Composite Materials. *Journal of Mechanical Engineering,* 2018, 68(1), 33 – 50.
5. Dayo, A. Q., Gao, B., Wang, J., Liu, W., Derradji, M., Shah, A. H., & Babar, A. A. (2017). Natural hemp fiber reinforced polybenzoxazine composites: Curing behavior, mechanical and thermal properties. *Composites Science and Technology*, 144, 114–124.
6. Dickson, A. N., Barry, J. N., McDonnell, K. A., & Dowling, D. P. (2017). Fabrication of continuous carbon, glass and Kevlar fibre reinforced polymer composites using additive manufacturing. *Additive Manufacturing*, 16, 146–152.
7. Senthamaraikannan, P., & Kathiresan, M. Characterization of raw and alkali treated new natural cellulosic fiber from Coccinia grandis.L. *Carbohydrate Polymers*, 2018, 186, 332–343.
8. Turcsan, T., & Meszaros, L. Mechanical performance of hybrid thermoset composites: Effects of matrix and reinforcement hybridization. *Composites Science and Technology*, 2018, 141, 32–39.
9. Bozkurt, Ö. Y., Erkliğ, A., & Bulut, M. Hybridization effects on charpy impact behavior of basalt/aramid fiber reinforced hybrid composite laminates. *Polymer Composites*, 2016, 39(2), 467–475.
10. Sivakumar, D., Ng, L. F., Lau, S. M., & Lim, K. T. Fatigue Life Behaviour of Glass/Kenaf Woven-Ply Polymer Hybrid Biocomposites. *Journal of Polymers and the Environment*, 2017, 26(2), 499–507.
11. Goh, G. D., Dikshit, V., Nagalingam, A. P., Goh, G. L., Agarwala, S., Sing, S. L., & Yeong, W. Y. Characterization of mechanical properties and fracture mode of additively manufactured carbon fiber and glass fiber reinforced thermoplastics. *Materials & Design*, 2018, 137, 79–89.
12. Arpitha, G. R., Sanjay, M. R., Senthamaraikannan, P., Barile, C., & Yogesha, B. Hybridization Effect of Sisal/Glass/Epoxy/Filler Based Woven Fabric Reinforced Composites. *Experimental Techniques*, 2017, 41(6), 577–584.