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TRIBOLOGICAL PROPERTIES OF HYBRID COMPOSITES BASED ON WOVEN CARBON FIBER/FINE KENAF FABRIC REINFORCED EPOXY MATRIX FOR AUTOMOTIVE APPLICATIONS

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Abstract

The demand for a combination of materials that satisfy the requirements of the world market has been exponentially growing in recent years. It is predicted that the upcoming years will guarantee a significant evolution of new classification of hybrid composite materials. The exploration of applicable alternatives to minimize the usage of synthetic fibers have led to the concepts of using both kinds of fibers as reinforcements to thermoset polymers. These highlight the fact that kenaf fibers are an emerging partial substitute to carbon fibers as reinforcements in polymer composites. Despite this interest, limited attention has been devoted to the quality of textile architecture of kenaf fabrics which eventually affects the overall properties of the laminated composites. The true challenge is to obtain more balanced properties in the fabric plane which can be achieved by appropriate fiber-matrix adhesion. Hence, using appropriate fabrication techniques the fundamental mechanisms of hybrid composites under different processing parameters and loading conditions may be understood and determined. In this work, interlacing layer hybrid composites were fabricated using vacuum infusion technique at which woven carbon and kenaf fibres were used as reinforcing agents with epoxy matrix. The volume fraction of fibre and thickness of hybrid composites varied from 40 vol.% to 50 vol.% and 3mm to 5 mm, respectively. In addition, four different sequences (CCCCC, KKKKK, KCKCK, CKCKC) were introduced. Mechanical testing including tensile test and flexural test were carried out according to ASTM D3039 and ASTM D790, respectively. Scanning Electron Microscope and Optical Microscope were used to determine the mode of failures in both tensile and flexural tests of carbon/kenaf hybrid composites. The optimization of mechanical properties was done using Design of Expert (DOE). Consequently, dry sliding wear and friction test was performed using Pin-On-Disc Tester. Under sliding conditions (applied loads and sliding speeds), the composite parameters (stacking sequences and compositions) greatly affected the tribological properties (coefficient of friction and wear rate) of these types of hybrid composites.

Key words: Hybrid composites, Tribology, Carbon Fibers, Kenaf Fibers, Mechanical

Introduction

Tribology is the science and technology of interacting surfaces in relative motion. It includes the study and application of wear, friction as well as lubrication principles. Metal has been widely used in various industries such as automotive, manufacturing, electronics and aerospace. Prior to application, the tribology performance has gained big interest. However, metals are found to be low resistant to corrosion and high density which contribute to a higher energy usage. Therefore, recently great attention is paid to the tribological study of polymer composites owing to their advantages such as lightweight, corrosion resistant and lower maintenance cost. One of the usage areas has been found to be advantageous in situations involving contact wear.

Composites, which consist of polymers with fillers either natural or synthetic fibers, are having properties of two materials together. The ratios of strength to weight and stiffness to weight are found to be several times stronger than steel or aluminium and also possible to achieve a combination of properties not attainable with metals, ceramics or polymer alone (Mohammed et al., 2015). These fibers will provide strength to the polymeric matrix and improve the tribological properties of fabricated composites. Natural fibers widely used as reinforcements in place of synthetic fibres in polymeric composites. Polymers have complex chemical structures, and therefore the tribological behaviour is difficult to predict (Nirmal et al., 2015). In fact, there are limited studies on natural fibre hybrid composites with woven structures and even fewer reports on the tribological properties of natural-synthetic hybrid composites (Sharba et al., 2016). Thus, outcomes of this study will contribute significantly to the tribological knowledge of kenaf/carbon hybrid composites.

Background

Composite materials have been immensely used for various applications in several industries such as automotive, aerospace, military, marine and construction. A composite material is (also called a composition material or shortened to composite, which is the common name) a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components (Rory, 2018). Composite materials are classified into three types based on the matrix which are metal matrix composites (MMC), ceramic matrix composites (CMC) and polymer matrix composites (PMC) (Callister, 2006).

In recent years, polymers and their composites are slowly replacing the conventional materials in many engineering applications (Arun, 2012). They are widely used due to their tailor-made properties. They provide some unique and better properties than the conventional materials such as light weight, better wear resistance, corrosion resistance, high strength, excellent stiffness and many more. Unfortunately, the high stiffness and strength of these composites come at the expense of their limited toughness (Yentl et al., 2014). Researchers discovered that the hybridization of composite systems can be implemented in order to improve the drawbacks of the composite materials. Hybrid composites are materials that are fabricated by combining two or more different types of fibers within a common matrix (Jamir et al., 2018). Hybrid composites can be made from artificial fibers, natural fibers and with a combination of both artificial and natural fibers (Nunna et al., 2012). Hybridization of natural fibres and synthetic fibres is an effective strategy to improve the strength, tribology and performance while expanding the field of application of the polymer composite.

Tribology is a science of two interacting surfaces in relative motion and encompasses friction, wear, lubrication, and related design aspects (Bijwe, 2015). The tribological analysis of a material is important as it can influence the life-span, fatigue strength and durability of the material. The tribological test is being done to obtain the wear rate and friction coefficient of the specimen. It is also carried out to observe and analyse the morphology on the surface of the sample. Several parameters that can affect the tribological behaviour of hybrid composite are applied load, sliding speed and time. Researchers have conducted some experiments and studies about the tribological behaviour of hybrid composite however, the data for optimization of tribological study is less explored.

Shankar et al. (2017) has performed a tribological test on several samples to study the wear properties. Based on the tribological test, it showed that when the concentration of the reinforcement increases, the wear rate decreases however when the speed and the sliding distance increase, the wear rate increases. According to Dalbehera et al. (2015), the difference in stacking sequences of the jute-glass epoxy hybrid composite will influence the erosion rate. The erosion rate will increase when the outermost or surface of the hybrid composite is glass fibre instead of jute fibre. In another study, Hashimi et al. (2007) has conducted an experiment to study the effect of friction and wear behaviour of cotton-graphite polyester hybrid composite at different applied loads and concentration of graphite. The result obtained from the experiment is the higher the composition of cotton fibre, the higher the coefficient of friction and the higher the composition of graphite, the lower the coefficient of friction.

However, replacing the synthetic fibre with natural fibre may change the properties of the hybrid composite such as mechanical, tribological and physical, either upgrading or downgrading the properties. Therefore, tribological behaviour and the optimization of the hybrid composite is analysed by using DOE method as wear on the surface of composite can cause failure in mechanical behaviour of a material. Tribological behaviour of hybrid composite is a crucial aspect as wear on the surface of composite can cause failure in mechanical behaviour of a material. Therefore, this study is aiming to resolve tribological issues in automotive application, by exploring the tribological behaviour of kenaf/carbon hybrid composite in search for the best configuration to reduce wear and friction to achieve a good tribological performance.

Objectives

The main objective of this study is to attain a tribological understanding of kenaf/carbon hybrid composite reinforced epoxy matrix with different types of stacking sequences and fiber content composition. In order to achieve the main objectives, several explicit objectives will be fulfilled as follows:

i. To propose optimum hybrid composite system utilizing fine textile architecture of woven kenaf fabric hybrid with woven carbon fiber reinforced epoxy matrix fabricated via vacuum infusion system approach validated using statistical model.
ii. To evaluate the mechanical, physical, morphological and thermal properties of the fabricated hybrid composites based on fiber- matrix ratio, stacking sequence and the fiber treatment parameters.
iii. To assess the tribological performances of the newly developed hybrid system prior to its applications.

Methodology

Materials

Kenaf fibers were supplied by Green Firm Bd., Bangladesh, received with an average thickness of 0.80 mm and 1.22 g/cm^3 density. Woven carbon fiber was supplied by Vistech Technology Services, Malaysia. It has 0.22 mm average thickness with 1.77 g/cm^3 density. The images and properties of kenaf and carbon fibers are shown in Figure 1 and Table 1, respectively. Epoxy resin grade INF-114 and curing agent grade INF-212 were supplied by Castmech Technologies Sdn. Bhd., Malaysia. The ratio of resin-to-hardener is fixed to 100:27.4 (g).

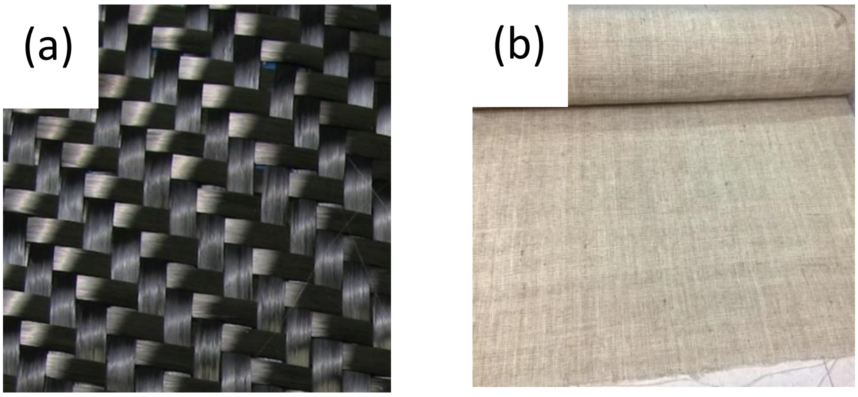


Figure 1: (a) 2x2 twill weave carbon fibre and (b) Fine woven kenaf fibre

Table 1: Properties of carbon fiber and kenaf fiber (data given by suppliers)

Properties	Materials	
	Kenaf fiber	Carbon fiber
Density (g/cm^3)	1.22	1.77
Thickness (mm)	0.22	0.80
Tensile strength (MPa)	200	1370-2070
Areal weight (gsm)	128	220
Pattern	Woven	Woven

Sample Preparation and Experimental Set-up

The process flow of the development of carbon/kenaf reinforced hybrid composite needs to be followed to achieve the desired final product. The experimental process flow is divided into several parts so that the objectives of this experiment will be fulfilled and achieved. Figure 2 shows the detailed experimental process flow of this project.

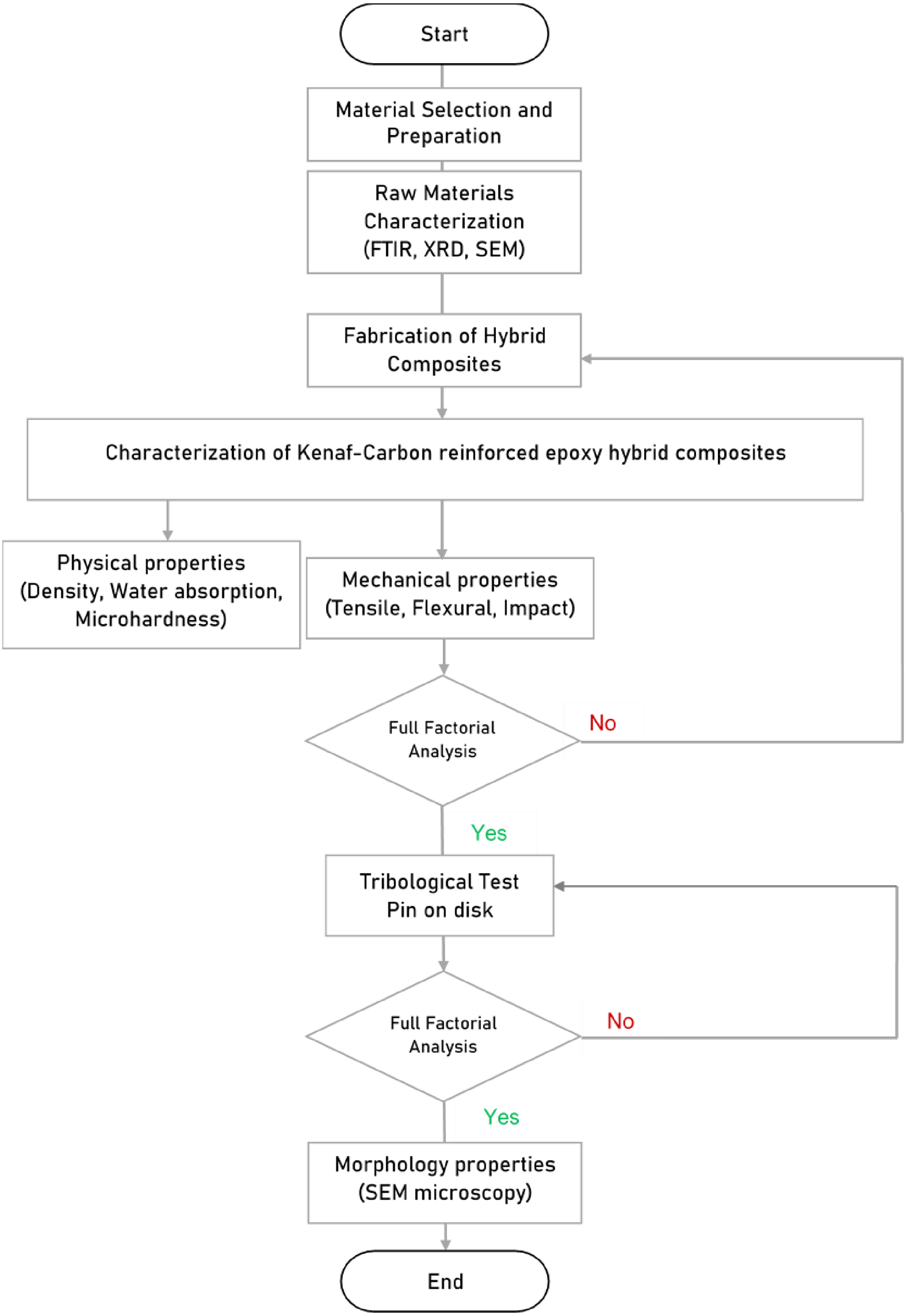
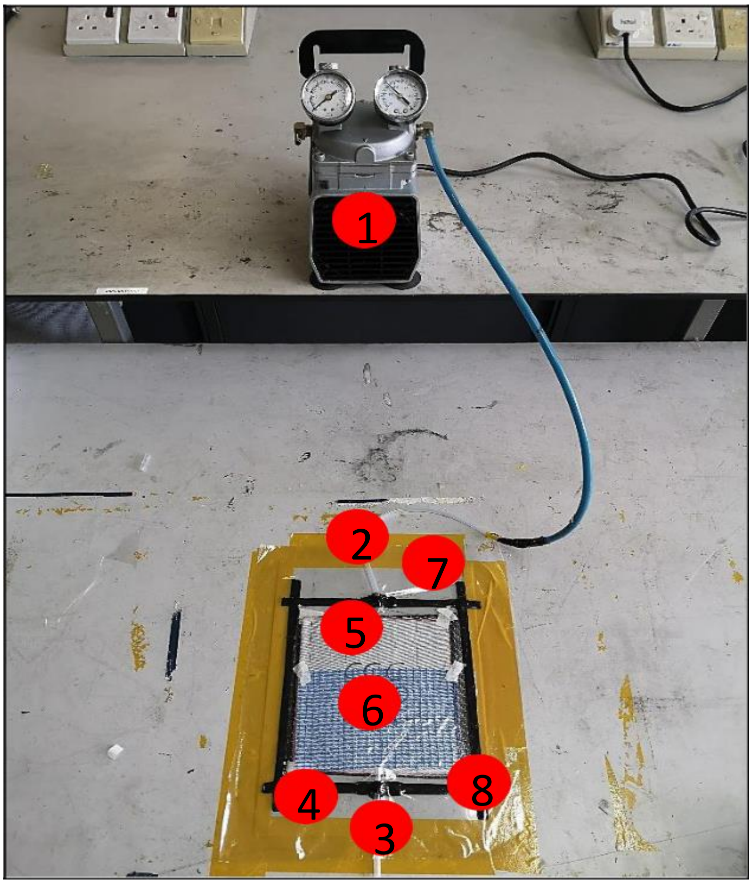


Figure 2: Flow chart of the experimental process

Kenaf/carbon hybrid composites will be prepared via vacuum infusion process. Calculated epoxy resin will be infused fully through the system at a constant pressure of 100 kPa. The process begins with stacking up the fibers, peel ply, mesh sheet and vacuum bag on the mould surface. The epoxy resin will be infused within the mould surface of kenaf and carbon fibers. A 24 hours curing process at room temperature will take place to solidify the hybrid composite panel before demoulding. All sets are to be designed to achieve 3 mm and 5 mm thicknesses. Figure 3 below shows vacuum infusion set up of kenaf/carbon hybrid composite samples. The hybrid composites will be fabricated in three sets of volumetric fiber content; 30, 40, and 50 vol. % with a ratio of kenaf to carbon at 1:1. Two non-hybrid stacking composite; CCCCC and KKKKK will be fabricated as reference samples, thereby as a control variable. Two hybrid stacking composite; CKCKC and CCKCC will be prepared as the hybrid composite samples. Figure 4 shows the stacking sequences sets of the hybrid composites.



1.Vacuum pump

2. Inlet chamber

3. Outlet chamber

4. Mylar sheet

5. Peel ply

6. Mesh sheet

7. Vacuum bag

8. Sealant tape

Figure 3: Experimental setup of vacuum infusion method

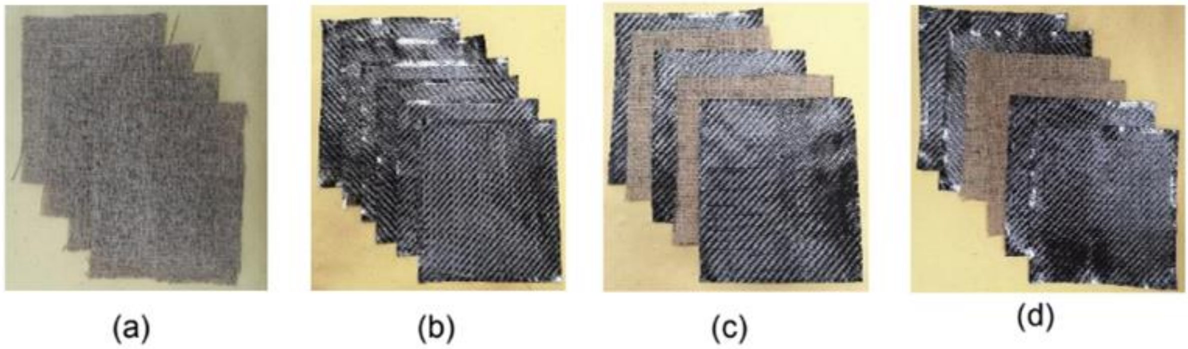


Figure 4: Stacking sequence (a) KKKKK, (b) CCCCC (c) CKCKC, and (d) CCKCC

Performance Evaluation of Kenaf/Carbon Hybrid Composites

Mechanical Test

Tensile test was performed using a Universal Testing Machine (Instron 5582) according to ASTM D3039. The samples were cut into a dimension of 250 mm × 25 mm. A crosshead speed of 2 mm/min with a load of 100 kN was applied during the tensile test. Five replicates were used to obtain average values for tensile strength and tensile modulus. Tensile fracture surfaces were analysed using a scanning electron microscope (SEM, JEOL 5400) at operating 10 kV.

Flexural test was conducted using a Universal Testing Machine (INSTRON 5582) based on ASTM D970. According to this ASTM standard, samples were prepared by having a dimension of 127 mm × 13 mm. A crosshead speed of 2 mm/min with a load of 100 kN. Five specimens were used to attain average values for flexural strength and flexural modulus. Flexural test failure modes were characterized using an optical microscope (Nikon Measuring Microscope Trinocular Head, model MM-TRF).

Impact test was performed using the Instron Izod impact machine according to ASTM D4812. The specimens were prepared by having a dimension of 64 mm × 12.7 mm with a thickness of 3 mm and 5 mm without notching. The value of impact strength was obtained by dividing each value of impact energy with the thickness of fabricated hybrid composites.

Tribological Experiments

A pin on disk machine was used to examine tribological performance of designed sets of kenaf/carbon hybrid composites. The dry adhesive wear test was conducted referring to ASTM G99 under designed parameter conditions according to the pin sliding movement on rotational disk (Figure 5). The loads applied at the wearing contact were varied at 5N, 10N and 15N and the relative sliding speed between the contacting surfaces are 2 m/s, 3.5m/s and 5m/s.

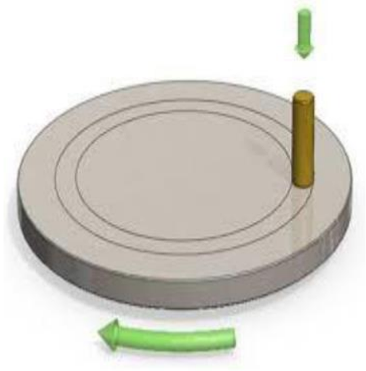


Figure 5: Schematic diagram of Pin on Disk set up.

Design of Experiment (DOE) Method

The software used to execute this experiment is Design Expert version 11 which provides the Design of Experiment (DOE) method. The Design of Experiment (DOE) method is used to identify and analyze the optimal design of hybrid composite and multifactor data of experiment. Response surface plot, interaction and the desirability were plotted and ANOVA data, diagnostic details as well as overall data report were analyzed.

Findings

Effect of Fiber Loadings and Stacking Sequences on Tensile Properties of Carbon-Kenaf Hybrid Composites

From the viewpoint of tensile properties, the highest tensile strength and modulus was found 210.49 MPa and 10.59 GPa belongs to hybrid composites that fabricated using 40 vol.% of fiber with stacking configuration of CKCKC (Appendix 1). This could be explained due to better lamination between fibers and matrix phase at this fiber content that consequently results in strong interfacial bonding between these constituents as shown in Appendix 2 (Mahjoub et al., 2014). It can be simplified that, from the perspective of fiber loading, the incorporation of fiber content from 30 vol.% to 40 vol.% tends to improve the tensile properties of fabricated hybrid composites. The addition of fiber content up to 50 vol.% prone to reduce the tensile properties of carbon-kenaf hybrid composites. Meanwhile, from the viewpoint of stacking sequences the assignation of carbon fiber as the outer layer, especially in CKCKC and CCKCC result in better tensile properties as compared to other types of stacking configuration, namely

CKCK and KCKCK. High strength of carbon fiber as a core layer can provide enough shield to CKCKC and CCKCC hybrid composite, thus, exhibit excellent stress endurance. The same agreement pointed by Salleh et al. (2013). Moreover, SEM micrographs reveal that better interfacial bonding between fibers and matrix able to be formed by hybrid composite that fabricated using 40 vol.% and CKCKC stacking sequence that consequently result in excellent tensile properties as compared to 30 vol.% and 50 vol.% hybrid composites (Appendix 3).

Effect of Fiber Loadings and Stacking Sequences on Flexural Properties of Carbon-Kenaf Hybrid Composites

The highest flexural properties displayed by hybrid composite that fabricated using 40 vol.% of fiber content with CCKCC stacking sequence where the value for flexural strength and flexural modulus were attained at 329.58 MPa and 31.88 GPa, respectively. Referring to Appendix 4, the flexural strength of hybrid composites at different stacking sequences shows an increasing trend when the amount of fibers increases from 30 vol.% to 40 vol.%. It is believed that the increment in flexural strength due to the adequacy of epoxy resin to bind carbon and kenaf fibers efficiently. Thus, the inclusion of fibers up to 40 vol.% enhances the load-bearing capacity and the competence to resist bending of the composite. A similar comment reported by Satapathy et al. (2009) and Harsha and Suresh (2010) from the previous studies. The declining trend in the flexural strength can be perceived when the amount of fiber loading increases to 50 vol.% in which this trend was found for all stacking sequences. Thus, the utilization of 50 vol.% fibers fail to provide the optimum reinforcing effect to the hybrid composite. Stress unable to be transferred effectively from matrix to the fiber. Thus, the failure in flexural testing of the carbon-kenaf hybrid composite at 50 vol.% is dominated by individual ply failure rather than interlaminar failure (Salman et al., 2016). As a result, the fabricated hybrid composites using 50 vol.% fibers incapable to withstand longer under the bending condition and lead to poor flexural strength. Referring to Appendix 5, the flexural failure starts to initiate from the bottom part of hybrid composites due to incapability of the upper part to maintain its structural integrity by separating the fibers and matrix, then promotes the appearance of fiber breakage failure. This failure was then propagated in the middle of hybrid composite panels then experienced the permanent flexural failure. It can be observed that, severe fiber breakage displayed by CKCK and KCKCK hybrid composites due to the assignation of weak kenaf fiber as the outer layer. Thus, it indicates that CKCK and KCKCK hybrid composites are unable to stay longer under flexural load that result in poor flexural properties.

Effect of Fiber Loadings and Stacking Sequences on Impact Properties of Carbon-Kenaf Hybrid Composites

The result shows that, hybrid composites fabricated using CCKCC stacking sequence display the highest impact in all-fiber loadings as compared to other types of stacking sequences where the values were attained at 1067 J/m, 1143 J/m, and 973 J/m for 30 vol.%, 40 vol.%, and 50 vol.%, respectively (refer Appendix 6). It is due to the strong outer skin that is occupied with several layers of carbon fibers. This finding is in accordance with the result obtained by Bakar et al. (2014). High stiffness behaviour of carbon fibers contributes to excellent fracture toughness in resisting impact loads. Strong fracture toughness of carbon fiber will slow down the spread of impact failures and cracks within the hybrid composite system and then, enable these types of hybrid composites to exhibit excellent absorbance of impact energy. Moreover, it can be noticeably seen that the addition of fiber content from 30 vol.% to 40 vol.% has improved the impact strength of fabricated carbon-kenaf hybrid composites where this trend was found in all stacking configurations. It is believed that enhancements in the stiffness have contributed to the rise in the impact strength of 40 vol.% carbon-kenaf hybrid composites. However, the stiffness behaviour of fabricated carbon-kenaf hybrid composites decreased when the amount of fiber content increased from 40 vol.% to 50 vol.%. This is due to the reduction in the impact strength of carbon-kenaf hybrid composites that are fabricated using 50 vol.% fiber loading where this reduction was found in all stacking sequences. The same finding recorded in open literature elsewhere in which impact strength has shown the decreasing trend with the increase in the fiber content up to 50 vol.% (El-Shekeil et al., 2012; Aji et al., 2011). The deployment of 50 vol.% fibers have disrupted the effectiveness of hybrid composites to absorb more impact energy and make these hybrid composites incapable of resisting more impact loads.

Effect of Thickness on Tensile Properties of Carbon-Kenaf Hybrid Composites

The values of tensile strength and tensile modulus of fabricated hybrid composites at two different thickness (3 mm and 5 mm) shown in Appendix 7 – Appendix 8. It can be spotted that 3 mm carbon-kenaf hybrid composites are able to display higher tensile strength and modulus than 5 mm hybrid composites. This finding was found in all-fiber content and stacking sequences. It is believed that a reduction in the tensile strength and modulus is also due to the introduction of more kenaf fibers in the hybrid composite system when the thickness changed from 3 mm to 5 mm, since the major obstacle in developing composite materials from natural fibers is poor compatibility with matrix resin. The poor attraction of kenaf fiber tends to interrupt the flow of epoxy resins within the layer of fibers. Thus, the formation of good lamination with a strong fiber-matrix interface is difficult to be formed for the thicker hybrid composite. As a result, this phenomenon led to the poor performance of tensile strength. The same agreement reported by Sandyal et al. (2019) in which hybrid composite with lesser thickness exhibit better tensile properties than the thicker hybrid composite. They have mentioned, at a high thickness fiber-fiber interaction becomes more dominant rather than fiber-matrix interaction. Thus, it affects the process of transferring the applied force from the epoxy matrix to the fibers. SEM micrographs show that, 5 mm carbon-kenaf hybrid composites suffered from severe tensile failure such as fiber pull-out and delamination as well as matrix cracking (refer Appendix 9). Moreover, it can be observed the presence of severe voids in 5 mm hybrid composites as shown in Appendix 9. Thus, it indicates that 5 mm hybrid composites are unable to resist high amounts of tension load and lead to poor tensile properties.

Effect of Thickness on Flexural Properties of Carbon-Kenaf Hybrid Composites

Appendix 10 represents the value of flexural strength and modulus of fabricated carbon-kenaf hybrid composites at 3 mm and 5 mm thickness. Increasing in thickness prone to worsen the distribution of resin within the layers of fibers. Natural fibers tend to display poor adhesion toward polymer matrices that consequently affect the lamination process of hybrid composites. Usually, incomplete-resin penetration process causes the formation of a high porosity that weakens its mechanical performances (Ferracane et al., 2017). Moreover, the formation of porosity also tends to facilitate the propagation of cracks within the composite panel and therefore, affects the mechanical aspect, including flexural behaviours of fabricated fiber-reinforced composites (Akonda et al., 2018). As a result, 5 mm hybrid composites tend to exhibit poor flexural properties. Based on fractography images (Appendix 11), hybrid composites with 5 mm thickness experienced severe flexural failures than 3 mm hybrid composites shown in Appendix 5. The most dominant flexural failures mode occurred in 5 mm hybrid composites encompassing fiber breakage and delamination. is believed that the appearance of delamination failure in the 5 mm carbon-kenaf hybrid composites due to the increment of kenaf fiber content inside the composite system, where kenaf fibers at middle part of hybrid composites tend to experience resin-starve phenomena in which they unable to receive sufficient resin. It causes the formation of hybrid composites with poor interfacial bonding. When the bending load was applied directly to the hybrid composite body, the load was carried individually by the fiber rather than the whole fibers in the hybrid composite system. Thus, cracks can penetrate easily inside the composite panel and therefore exposes the system to experience severe delamination.

Effect of Thickness on Impact Properties of Carbon-Kenaf Hybrid Composites

From the perspective of comparative analysis, 5 mm hybrid composites display slightly higher in impact strength as compared to 3 mm hybrid composites (Appendix 12). The increment in the impact strength can be related to the ability of fabricated fiber-reinforced composite toward stiffness bending (Reddy et al., 2019). Thicker fiber-reinforced composites will have adequate stiffness bending to resist the effect from low-velocity impact in which enough stiffness bending will delay the sample from permanent failure and therefore, resulting in a high impact strength.

Optimization on Mechanical Properties of Carbon-Kenaf Hybrid Composites

The optimization was carried out by analysing the overall desirability of manufactured hybrid composites with the combinations of different factors. It should be noted that the overall desirability was computed based on the combination of three responses, including tensile strength, flexural strength, and impact strength. The DOE optimization ranked the hybrid composite from the highest desirability to the lowest desirability. Therefore, Appendix 13 shows the result that was gained from the DOE optimization analysis. The highest desirability recorded at 0.826 that is equivalent to 82.60% belongs to carbon-kenaf hybrid composite with the parameters of 40 vol.% fiber content, 3 mm thickness, and type 3 (CCKCC) stacking sequence. The desirability of factors and responses for the selected hybrid composite is illustrated in Appendix 14. It can be perceived that for the selected optimum factors that consist of 40 vol.% fiber content, 3mm thickness, and type 3 stacking sequence, the individual desirability for tensile strength, flexural strength, and impact strength recorded at 0.733704, 0.740273, and 0.969478 respectively. Then, the overall desirability of 0.826485 was obtained from the combination of these individual desirability. It worth to be mentioned that the overall desirability that attained in the current study can be considered as an acceptable value since it involves manipulations of more than one factors, thus, many conditions need to be counted since different factor may contribute to different behaviour of responses (Ayaz et al., 2018; Paredes et al., 2019). Once the optimum factor has been fixed and the predicted values for each of the responses were obtained, the validation process took place by fabricating the hybrid composite panel based on suggested parameters. All the mechanical testing that involved, including tensile, flexural, and impact tests were performed accordingly. The DOE analysis estimated that, at this condition, the tensile strength, flexural strength, and impact strength reached the value of 181.839 MPa, 265.472 MPa, and 1149.08 J/mm, respectively. The mechanical results gained from mechanical tests are presented in Appendix 15. The results show that the experimental values for tensile, flexural, and impact strengths were obtained at 202.72 MPa, 299.31 MPa, and 1150 J/mm, respectively. It is significant to note that, these values are in a range of predicted values generated from DOE optimization. Thus, it indicates, the optimization is successful and acceptable, where the developed empirical model is acceptable for predicting the mechanical properties of carbon-kenaf hybrid composites.

Tribological Analysis of Hybrid Composite

Appendix 16 shows the variations in coefficient of friction when samples of hybrid composites (CCKCC) run at different sliding speeds. Coefficient of friction indicates the amount of force required to move two sliding surfaces and it also can be defined as the force that holds them together. The value for coefficient of friction usually lies between 0-1. When the value of COF is 0, it means that there is no friction existing in the system. For 200 rpm speed, COF value starts with 0.7 and starts to reduce to 0.6 with small fluctuation along the time. Next, for speed 350 rpm the COF result is quite comparable with 200 rpm speed. The COF value for 350 rpm starts with 0.9 and after 100 seconds, the value starts to drop and lies around 0.4 to 0.6. Lastly, for speed C the COF value undergoes a significant drop from 0.6 to value that lies between 0 and 0.1. It clearly can be seen from the graph that the coefficient of friction value starts to decrease when the sliding speed is higher. It is worth mentioning that increasing speed results in faster sliding on the counter surface, which causes less frictional force. This is due to the formation of tribo oxide film at the mating surfaces. The tribo oxide film usually forms at a plastic zone that will soften the mating surfaces and cause some drops towards COF value.

Appendix 17 shows the coefficient of friction for CCKCC hybrid samples sliding under constant load of 30N. The graph shows some significant effect of loads towards the COF values. The coefficient of friction value for speed 200 rpm, speed 350 rpm and speed 500 rpm start with 0.65. At below 250 seconds, COF value for those speeds lies between 0.3 –0.65. These high COF values are due to the surface roughness of samples at early stages of the sliding process that bring to the imperfect contact between samples and disc (Mohanta, 2017). Then from 300 seconds to 600 seconds, the COF value for 200 rpm starts to maintain at 0.25 and for 350 rpm speed, value of COF drops little bit to 0.2 with small fluctuation and lastly for 500 rpm speed, value of COF lies between 0.1 and 0.2. The effect of loads can be seen when all of three speeds recorded lower coefficient of friction at the end of sliding time. This trend might be due to larger load applied that caused high production of carbon debris during the sliding process. This carbon debris creates a lubricant effect that will soften the mating surface and totally cause the decreasing of COF value.

Appendix 18 shows the wear rate comparison between hybrid composite (CCKCC & CKCKC), CCC and KKK. By using constant load B (20 N), the effect of speed towards wear rate was observed. It can be seen that, at the lower speed of 200 rpm, CKCKC, CCC & KKK composites experienced higher value of wear rate. This might be due to thermal softening of epoxy resin that is caused by heat inducing at the contact area as temperature at the surface of samples and disc. Increasing the temperature at the contact area allowing for easier abrasion and ploughing that will result in higher wear rate. However, CCKCC shows a deviation from the expected result especially when speed is 350 rpm. The value of wear rate recorded was 1.193 x 10-7mm3 /m. This might be due to the delaminations that occur during the sliding test. The presence of kenaf fibre in the middle of CCKCC sequence results in poor adhesion between fibres and epoxy matrix compared to CKCKC sequence (Nitish, 2019). It was also observed that the increase in speed lead to decrease of wear rate value for most of the composites. CCC previously recorded 1.025 x 10-7 mm3 /m have dropped significantly to 0.749 x 10-7 mm3 /m after increasing speed. Hybrid composite with sequences of CKCKC and KKK also shows some decreasing value in wear rate. This might be due to tribo-oxide layer formation when the composites already enter the plastic zone. As stated by Wang (2016), the increasing in thickness of the tribo-oxide layer will occur parallel with increasing sliding speed.

Referring to Appendix 19, it shows the effect of load towards wear rate for hybrid composite with difference sequence. From the graph, it clearly can be seen that CKCKC recorded a lower wear rate compared to CCKCC. The sequence of CKCKC is expected to have better adhesion between carbon fibres, kenaf fibres and also epoxy that lead to better resistance of wear. The wear rate value for both sequences drop significantly with increasing load. For CCKCC, the value of wear rate dropped from 1.336 x 10-7 mm3 /m to 0.755 x 10-7 mm3/m while CKCKC from 0.671 x 10-7 mm3 /m to 0.081 x 10-7 mm3 /m. In many cases, the amount of load increase will lead to the higher wear rate value. But in this case, wear rate decreases when the amount of load increases. This might be due to the sample that already undergoes some fracture during the early stage of sliding rotation when higher load was applied. This fracture or damage is expected to cause imperfect contact between the samples composites and also the disc. This imperfect contact causes the value of coefficient of friction drops and totally leads to the decreasing value of wear rate.

Wear Analysis of Hybrid Composites

The fractography of the failure surface of wear test samples were observed under Scanning Electron Microscopy (SEM). Referring to Appendix 20 (a), it can be seen that samples show smooth and pore free surfaces which indicate consistent sliding contact between discs and also sample. However, there are still some defects that occur at the surface which cause some fibres breakage. For Appendix 20 (b), it was clearly visible that some fibres were pulled out. These occurrences are responsible for the high coefficient of friction for CCKCC samples. From Appendix 20 (c), there are few voids that can be observed. It clearly can be seen that the fracture and rough surface exist at most part of the samples. These rough and inconsistent surfaces might due to abrasion wear that cause epoxy soften and this lead to high value of wear rate recorded. From Appendix 20 (e) and (f), it shows some smooth surface while at the same time, fibres pull out also can be seen on the surface This might be due to imperfect contact between disc and rough samples. Formation of rough surface on samples is due to the cutting process during the preparation part. At higher magnification (1500x), the existence of debris can be seen and the interface reaction between epoxy resin and also fibres is good when most of the fibres are attached well with the epoxy resin. The existence of debris can act as lubricant that could reduce the amount of wear rate. Lastly, Appendix 20 (g) and (h) show a smooth surface with some void and fibre pull out on the surface of the samples. However, there is still good adhesion between kenaf fibres, carbon fibres and epoxy during the sliding process. It can be claimed that higher sliding speed will produce a smoother surface than lower sliding speed.

The failure mode of composite samples after being subjected to wear tests were examined by an optical microscope. From Appendix 21 (a), the surface of hybrid composite (CCKCC) is smooth with only a small void located at the middle of sample. This smooth surface without larger crack can be attributed to the self-sustaining layer formed due to synergistic effect between carbon fibres, kenaf fibres and epoxy matrix. For Appendix 21 (b), the existence of fibre pull out and fibre fracture clearly can be seen. This may be due to high load and lower speed applied on this sample compared to previous sample in Appendix 21 (a). Appendix 21 (c) and (d) shows comparison between hybrid composite (CCKCC) that have been applied with different speed but same load. From Appendix 21 (c), it shows some holes fracture while for sample in Appendix 21 (d) show only small void. This might due to the effect of lower speed that contributes to higher wear rate. The same trend was recorded in Appendix 21 (e) and (f). For these figures, samples used were hybrid composite with sequences of CKCKC. High speed effect totally can reduce the occurrence of hole fracture on surface's samples. However, there are still some minor defects that occur for example fibre pull out and crack on the surface. This might be due to the limited amount of epoxy matrix at the interfaces due to presence of large amounts of carbon fibres and kenaf fibres. Lastly, for Appendix 21 (g) and (h) there are some minor defects detected. For Appendix 21 (g), there is only micro crack at the middle of the sliding surface. This shows good adhesion between carbon fibre and also epoxy matrix. From Appendix 21 (h), it clearly can be seen that kenaf fibres still laminate well with epoxy matrix although undergo sliding condition. This could be supporting evidence that the choice of kenaf fibres to cooperate with carbon fibres is suitable in order to reduce samples wear in this study.

Financial Report and Asset Report

Table 2 shows the financial report and Table 3 displays the detail of asset.

Table 2: Financial report

Vote Code	Description	Allocation (RM)	Disburse (RM)	Commit (RM)	Balance (RM)
V11000	Research Assistant (RA)	43,000.00	42,000.00	0.00	1,000.00
V21000	Travelling Expenses And Subsistence	5,000.00	703.70	0.00	4,296.30
V23000	Communication and Utilities	0.00	0.00	0.00	0.00
V24000	Rental	0.00	0.00	0.00	0.00

Vote Code	Description	Allocation (RM)	Disburse (RM)	Commit (RM)	Balance (RM)
V27000	Research Materials & Supplies	10,500.00	27,748.61	0.00	-17,248.61
V28000	Maintenance services	10,000.00	0.00	0.00	10,000.00
V29000	Professional Services & Other Services including Printing & Hospitality, Honorarium for subjects	10,000.00	9,582.30	2,000.00	-1,582.30
V35000	Equipment	10,000.00	2,491.00	0.00	7,509.00
V36000	Miscellaneous Research Advancement	0.00	0.00	0.00	0.00
Total		**88500.00**	**82525.61**	**2000.00**	**3974.39**

Table 3: Detail of asset

Type of Asset	OIL-LESS DIAPHRAGM PUMP
Brand of Asset	GAST (U.S.A)
Cost of Asset (RM)	2,491.00
Asset Serial Number	
Equipment Serial Number	116007375
Date of Procurement	26/01/2018

Conclusion

Carbon-kenaf reinforced epoxy matrix hybrid composites successfully fabricated using vacuum infusion method. From the research, it can be concluded that:

i. The screening DEO was successfully performed. Based on this process, three fixed parameters have been identified consisting of fiber content, thickness, and stacking sequences. The fabrication of carbon-kenaf hybrid composites based on these three parameters – fiber content made from three different fibers' composition (30 vol.%, 40 vol.%, and 50 vol.%), two different thicknesses (3 mm and 5 mm), and four variations of hybrid stacking sequences (CKCKC, CCKCC, CKCK, and KCKCK).

ii. Experimentally, the evaluations on mechanical and physical properties of carbon-kenaf hybrid composites showed that:
   - The highest tensile strength and modulus obtained when carbon-kenaf hybrid composites fabricated using 40 vol.% fiber content, 3 mm thickness, and CKCKC stacking configuration where tensile strength and modulus have improved by 63.58% and 78.19%, respectively as compared to the reference kenaf composite.
   - The highest flexural properties found when 40 vol.% fiber content, 3 mm thickness, and CCKCC were selected as parameters for the fabrication of hybrid composites. Flexural strength and modulus have improved by 78.76% and 71.89%, respectively compared to the kenaf composite.
   - The utilization of 40 vol.% fiber content, 5 mm thickness, and CCKCC stacking sequence result in excellent impact strength in which this value has increased by 49.26% as compared to the reference kenaf composite.

iii. The DOE via full factorial model revealed that the optimum mechanical properties (tensile, flexural, and impact properties) of fabricated carbon-kenaf hybrid composites able to be achieved by utilizing parameters of 40 vol.% fiber content, 3 mm thickness, and CCKCC stacking configuration. The validation process showed that the experimental values for tensile strength, flexural strength, and impact strength were in the range of predicted values given by DOE optimization. Thus, it indicates the developed model is successful and acceptable in predicting and optimizing the mechanical properties of carbon- kenaf reinforced epoxy hybrid composites.

iv. The effect of speed towards COF and wear rate can be seen where higher sliding speed will lead to decreasing value of COF and wear rate. This is due to the formation of a tribo oxide layer and also debris that can act as lubricant between samples and disc. Next, COF and wear rate values are also influenced by load applied during the sliding process. Higher load applied will increase the amount of wear rate due to fibre breakage that easily occurs during the sliding process. The tribological properties of CKCKC showed lower value of coefficient of friction (COF) and wear rate compared to CCKCC due to difference stacking sequence. The hybrid of CKCKC shows good interfacial adhesion between fibres and matrix that contribute to the better performance of tribological properties. In addition, CKCKC shows less fibre pull-out and micro-crack under micrograph analysis.

Output

a) Human Capital Development

PhD:

1. Name of Student: Siti Norbahiyah binti Mohamad Badari
   IC/Passport No: 830113086406
   Student ID: G1821982
   Citizenship: Malaysian
   Year & Status: 2020 - Present (On-going)
   Thesis Title: Tribology of Kenaf/Carbon Fiber Reinforced Epoxy Hybrid Composites

Master:

1. Name of student: Mohamad Ikhwan bin Yusuff
   IC/Passport No: 940202115069
   Student ID: G1818327
   Citizenship: Malaysian
   Year of Graduation: 2020
   Thesis Title: Optimization and Prediction on Mechanical Properties of Carbon-Kenaf Hybrid Composites using Full-Factorial Approach

FYP:

1. Name of student: Muhammad Fawwaz Ariff bin Mohd Jamaluddin
   IC/Passport No: 980928565145
   Student ID: 1714561
   Citizenship: Malaysian

Year: 2020 (On-going)

Project Title: Effect of Sliding Wear Condition on the Wear Behaviour of Hybrid Composite Materials

2. Name of Student: Nurul Atikah Binti Hamdan Sharuhil
   IC/Passport No: 970318085962
   Student ID: 1622492
   Citizenship: Malaysian
   Year: 2020 (On-going)
   Project Title: Prediction and Optimization on Tribological Behaviour of Carbon/ Kenaf Hybrid Composite

3. Name of Student: Ahmad Irfan Bin Zaimi
   IC/Passport No: 960805115429
   Student ID: 1615059
   Citizenship: Malaysian
   Year of Graduation: 2020
   Project Title: Tribological Properties of Carbon/Kenaf Fiber Reinforced Epoxy Hybrid Composites

4. Name of Student: Nur Hazimah Binti Zainal Abidin
   IC/Passport No: 950724055058
   Student ID: 1420512
   Citizenship: Malaysian
   Year of Graduation: 2019
   Project Title: Physical and Mechanical Properties of Carbon/Kenaf Fiber Reinforced Polymer Composites

5. Name of Student: Atiqah Binti Abd Rahman
   IC/Passport No: 941216025878
   Student ID: 1411296
   Citizenship: Malaysian
   Year of Graduation: 2018

Project Title: Hybrid Composites of Fine Kenaf Fabric and Woven Carbon Fiber Reinforced with Epoxy Matrix

b) Publication

I Yusuff, N Sariffudin, A Mohd Ali, H Ismail, S Norbahiyah (2020). Effect of Stacking Sequences on Mechanical Properties of Kenaf Hybrid Composites. Materials Science Forum 1010, 459-464. (Scopus)

Ikhwan Yusuff, Norshahida Sarifuddin, S. Norbahiyah, Afifah Mohd Ali and Hanafi Ismail (2020). Tensile and Flexural Properties of Woven Carbon-Kenaf Fiber Reinforced Epoxy Matrix Hybrid Composite: Effect of Hybridization And Stacking Sequences. AIP Conference Proceedings 2267, 020026 DOI: 10.1063/5.0015682 (Scopus)

I Yusuff, N Sarifuddin, AM Ali (2020). A Review on Kenaf Fiber Hybrid Composites: Mechanical Properties, Potentials, And Challenges in Engineering Applications. Progress in Rubber Plastics and Recycling Technology, 1-18 (IF=0.742)

I Yusuff, N Sarifuddin, AM Ali, FDM Daud, S Norbahiyyah (2020). A Comparative Study on Mechanical Properties of Carbon and Kenaf Composites via Vacuum Infusion Technique. Journal of Engineering Science, Vol. 16 (1), 97–107 ISSN: 2180-4214 (Genamics JournalSeek, Google Scholar, MyJurnal, ProQuest, WorldCat)

Mohamad Ikhwan Yusuff, Norshahida Sarifuddin and Zuraida Ahmad (2019). Mechanical Properties of Woven Carbon Fiber/Kenaf Fabric Reinforced Epoxy Matrix Hybrid Composites. Malaysian Journal of Microscopy Vol. 15 (2019), Page 10-16. (Scopus)

c) Intellectual Property

None

d) Additional Output

Ikhwan Yusuff, Norshahida Sarifuddin, S.Norbahiyah, Afifah Mohd Ali and Hanafi Ismail. Tensile and Flexural Properties of Woven Carbon-Kenaf Fiber Reinforced Epoxy Matrix Hybrid Composite: Effect of Hybridization and Stacking Sequences. Presented in 3rd International Postgraduate Conference on Materials, Minerals & Polymer (MAMIP) 2019, 31 October - 1 November 2019, School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia. (Paper published in AIP Conference Proceedings)

Ikhwan Yusuff, Norshahida Sariffudin, Afifah Mohd Ali, Hanafi Ismail, S Norbahiyah. Effect of Stacking Sequences on Mechanical Properties of Kenaf Hybrid Composites. Presented in Conference on Advanced Materials Characterization Technique 2019 (AMCT2019), 23rd – 24th July 2019 at Putra Regency Hotel, Kangar, Perlis, Malaysia. (Paper published in Materials Science Forum)

Mohamad Ikhwan Yusuff, Norshahida Sarifuddin and Zuraida Ahmad. Mechanical Properties of Woven Carbon Fiber/Kenaf Fabric Reinforced Epoxy Matrix Hybrid Composites. Presented in 27th Scientific Conference Microscopy Society of Malaysia (SCMSM 2018), 3 – 4 December 2018, The Mudzaffar Hotel, Melaka, Malaysia. (Paper published in Malaysian Journal of Microscopy)

Norshahida Sarifuddin, Hanafi Ismail, Zuraida Ahmad and Atiqah Rahman. Hybrid Composites of Woven Carbon Fiber / Fine Kenaf Fabric Reinforced Epoxy Matrix. Oral presenter in Kathmandu Symposia on Advanced Materials - 2018 (KaSAM - 2018) October 26-29, 2018, Kathmandu, Nepal.

Future Plan of the research

The present research has explored the possibilities of combining two different types of fibers (synthetic fiber and natural fiber), specifically carbon fiber and kenaf fiber with polymer resin in the composite materials for structural use, especially automotive application. Therefore, further validations and explorations on the developed carbon-kenaf hybrid composite are needed for acquiring better results and findings so that the potential of this composite material can be fully utilized. As such, recommendations for future works are:

1. Better surface treatment on both fibers (carbon fiber and kenaf fiber) can be performed so that the physical and mechanical properties of manufactured hybrid composites can be improved. For example, plasma treatment on the surface of carbon fiber and alkali treatment on the surface of kenaf fiber can make the fibers' surface become rougher, then allow the matrix to make better bonding with fibers. As a result, high mechanical properties are able to be attained. Moreover, proper treatment on the surface of kenaf fiber can also reduce the high-water absorption behaviour of this natural fiber.
2. A better understanding of the wear properties of carbon-kenaf hybrid composites should be considered since the main application focuses on structural use, especially car bumpers. Therefore, the evaluation of the tribology behaviours of hybrid composites can be done so that the information regarding wear mechanism can be attained and match with the existing product.
3. In the future, the mechanical results obtained from the optimization model should be compared with the real industrial product (automotive part) such as car bumpers to ensure the reliability and durability of the fabricated composite. Therefore, collaboration and attachment with the automotive industry are necessary to expand the wider acceptability of carbon-kenaf hybrid composites as one of the potential materials in this industry.

References

Aji, I. S., Zainudin, E. S., Khalina, A., Sapuan, S. M., and Khairul, M. D. (2011). Studying the effect of fiber size and fiber loading on the mechanical properties of hybridized kenaf/PALF-reinforced HDPE composite. Journal of Reinforced Plastics and Composites, 30(6), 546–553.

Akonda, M., Alimuzzaman, S., Shah, D. U., and Rahman, A. N. M. (2018). Physico-Mechanical, Thermal and Biodegradation Performance of Random Flax/Polylactic Acid and Unidirectional Flax/Polylactic Acid Biocomposites. Fibers, 6(4), 1-14.

Arun, K., Rout, & Satapathy, A. (2012). Study on mechanical and tribo-performance of rice-husk filled glass–epoxy hybrid composites. Materials & Design, 41, 131–141. doi:10.1016/j.matdes.2012.05.002

Ayaz, M., Ghasemi, F. A., Rahimloo, V. P., and Saman, M. (2018). Multi-response optimization of the mechanical properties of PP/talc/CaCO3 ternary nanocomposites by the response surfacemethodology combined with desirability function approach. Journal of Elastomers & Plastics, 2018, 1 - 20.

Bakar, N. H., Hyie, K. M., Ramlan, A. S., Hassan, M. K., and Jumahat, A. (2014). Mechanical Properties of Kevlar Reinforcement in Kenaf Composites. Applied Mechanics and Materials, 465-466, 847–851.

Bijwe, J. (2015). Multifunctionality of nonasbestos organic brake materials. Multifunctionality of Polymer Composites, 551–572. doi:10.1016/b978-0-323-26434-1.00017-9

Callister, W. D. (2006). Material science and engineering: an introduction. 7th ed. Wiley.

El-Shekeil, Y. A., Sapuan, S. M., Abdan, K., and Zainudin, E. S. (2012). Influence of fiber content on the mechanical and thermal properties of Kenaf fiber reinforced thermoplastic polyurethane composites. Materials & Design, 40, 299–303.

Ferracane, J. L., Lohbauer, U., and Palin, W. M. (2017). Understanding the mechanical behavior of the material–tissue and material–material interface in dental reconstructions. Material-Tissue Interfacial Phenomena, 113–145.

Harsha, A. P. and Arjula, S. (2010). Influence of fibre orientation on three-body abrasive wear behaviour of unidirectional carbon fibre-reinforced polyetherimide composite. Journal of Materials Science, 46(4), 983–991.

Hashmi, S. A. R., Dwivedi, U. K., & Chand, N. (2007). Graphite modified cotton fibre reinforced polyester composites under sliding wear conditions. Wear, 262(11-12), 1426–1432. doi:10.1016/j.wear.2007.01.014

Jamir, M. R. M., Majid, M. S. A., & Khasri, A. (2018). Natural lightweight hybrid composites for aircraft structural applications. Sustainable Composites for Aerospace Applications, 155–170. doi:10.1016/b978-0-08-102131-6.00008-6.

Mohammed, L., Ansari, M. N. M., Pua, G., Jawaid, M., & Islam, M. S. (2015). A Review on Natural Fiber Reinforced Polymer Composite and Its Applications. 2015.

Mahjoub, R., Yatim, J. M., Mohd Sam, A. R., and Hashemi, S. H. (2014). Tensile properties of kenaf fiber due to various conditions of chemical fiber surface modifications. Construction and Building Materials, 55, 103–113.

Nirmal, U., Hashim, J., & Ahmad, M. M. H. M. (2015). Tribology International A review on tribological performance of natural fibre polymeric composites. Tribology International, 83, 77–104. https://doi.org/10.1016/j.triboint.2014.11.003

Nunna, S., Chandra, P. R., Shrivastava, S., & Jalan, A. (2012). A review on mechanical behavior of natural fiber based hybrid composites. Journal of Reinforced Plastics and Composites, 31(11), 759–769. doi:10.1177/0731684412444325

Paredes, J., Vaca, H., Erazo, H., and Pérez, C. (2019). Multi-Response Optimization of Mechanical Properties of Hybrid (Fiberglass / Abaca Woven) in Polyester Matrix using Desirability Function based on DOE. IOP Conference Series: Materials Science and Engineering, 473, 012020.

Reddy, T. S., Mogulanna, K., Reddy, K. G., Subba Reddy, P. R., and Madhu, V. (2019). Effect of thickness on behaviour of E-glass/epoxy composite laminates under low velocity impact. Procedia Structural Integrity, 14, 265–272.

Rory, R. (2018). *Inorganic chemistry*. Waltham Abbey, United Kingdom: ETP.

Salleh, Z., Hyie, K. M., Berhan, M. N., Taib, Y. M., Hassan, M. K., and Isaac, D. H. (2013). Effect of Low Impact Energy on Kenaf Composite and Kenaf/Fiberglass Hybrid Composite Laminates. Applied Mechanics and Materials, 393, 228–233.

Salman, S. D., Leman, Z., Thariq, M., Sultan, H., and Cardona, F. (2016). The Effect of Stacking Sequence on Tensile Properties of Hybrid Composite Materials. Malaysian Journal of Civil Engineering, 28(1), 10–17.

Sandyal, P., Sreenath, N., Lavakumar, and Sandyal, A. (2019). Effect of Strain Rate Thickness on Mechanical Properties of Jute/Glass Hybrid Fiber Composites. International Research Journal of Engineering and Technology (IRJET), 6(8), 269 - 275.

Satapathy, A., Alok Kumar Jha, Mantry, S., Singh, S. K., and Patnaik, A. (2009). Processing and Characterization of Jute-Epoxy Composites Reinforced with SiC Derived from Rice Husk. Journal of Reinforced Plastics and Composites, 29(18), 2869–2878.

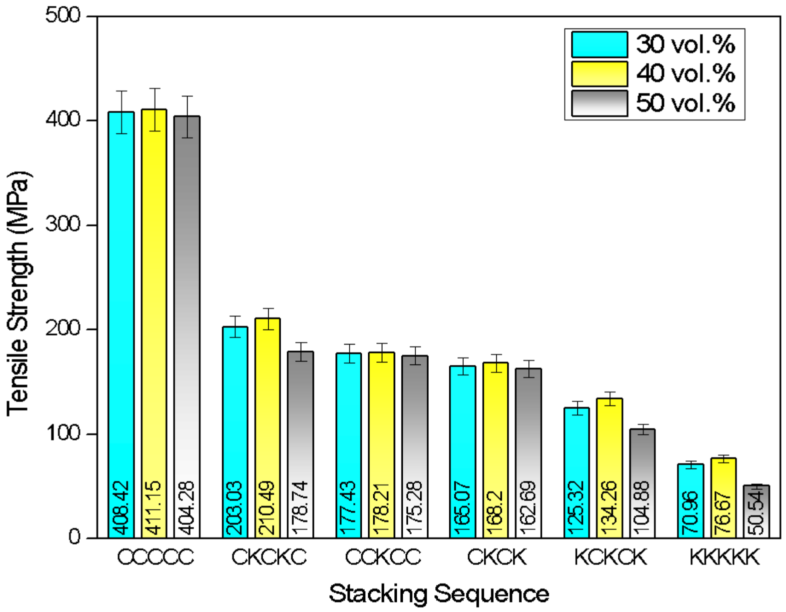
Sharba, M., Putra, U., Universiti, L., Analysis, A. E., Mechanisms, D., & View, C. (2016). Partial Replacement of Glass Fiber by Woven Kenaf in Hybrid Composites and its Effect on Monotonic and Fatigue Properties Partial Replacement of Glass Fiber by Woven Kenaf in Hybrid Composites and its Effect on Monotonic and. February. https://doi.org/10.15376/biores.11.1.2665-2683

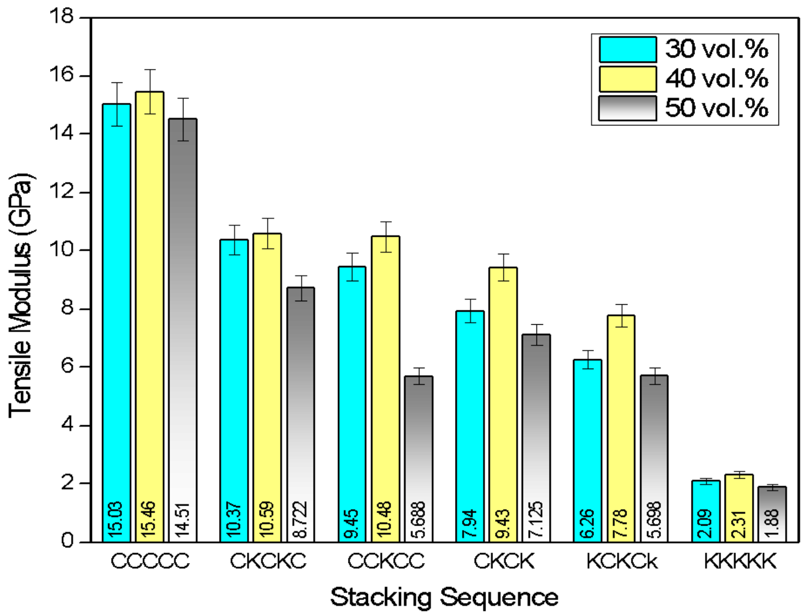
T. Shankar, T. Narendiranath Babu, R. Mageshvaran, and D. Rama Prabha, Specific Wear Rate of Epoxy Resin Based Composites Reinforced with Natural Fibers and Uni-Axial Glass Fibers for Bio Medical Applications. International Journal of Civil Engineering and Technology, 8(3), 2017, pp. 729–740.

Yentl, S., Gorbatikh, L., & Verpoest, I. (2014). Fibre hybridisation in polymer composites: A review. Composites Part A: Applied Science and Manufacturing, 67, 181–200.

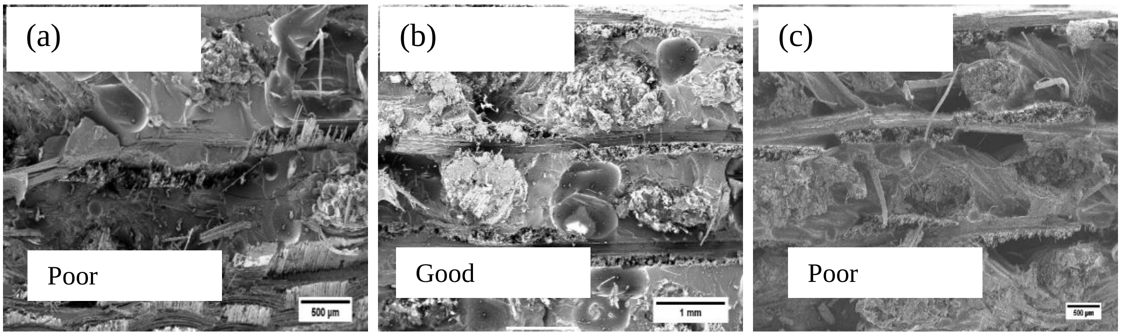
Appendix

Appendix 1: Tensile strength and tensile modulus of fabricated carbon-kenaf hybrid composite at various fiber content and stacking sequences

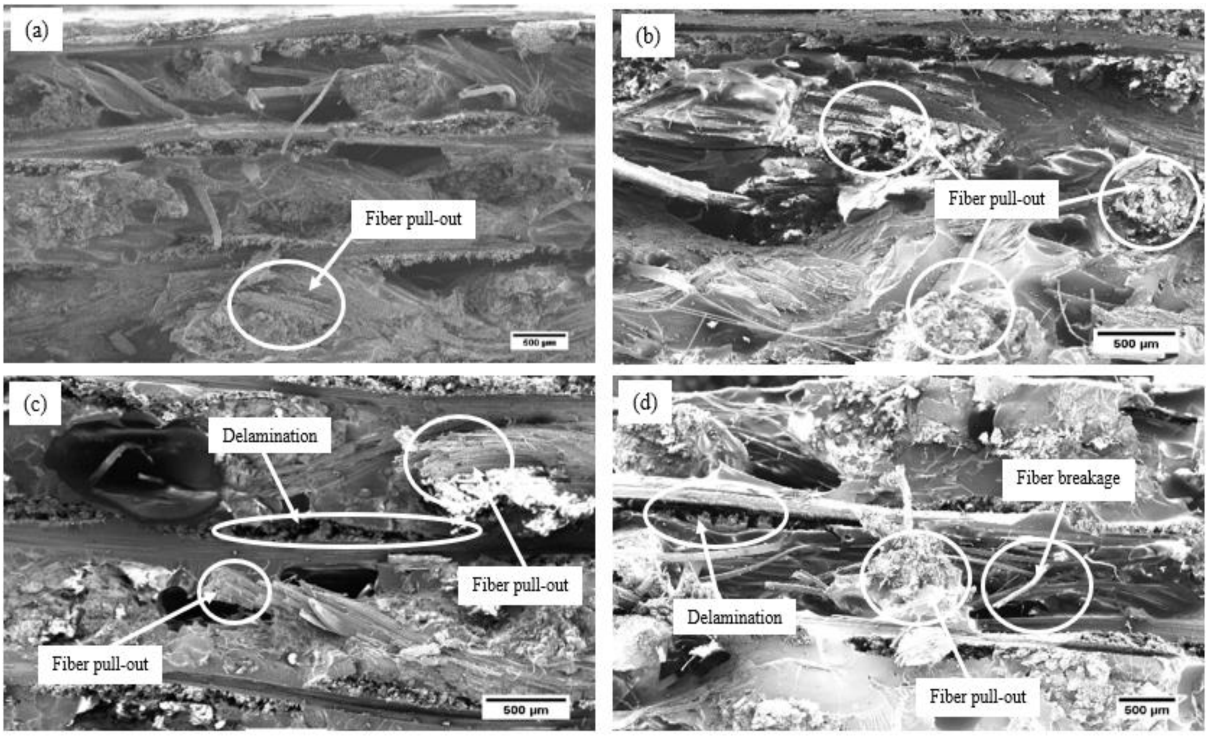




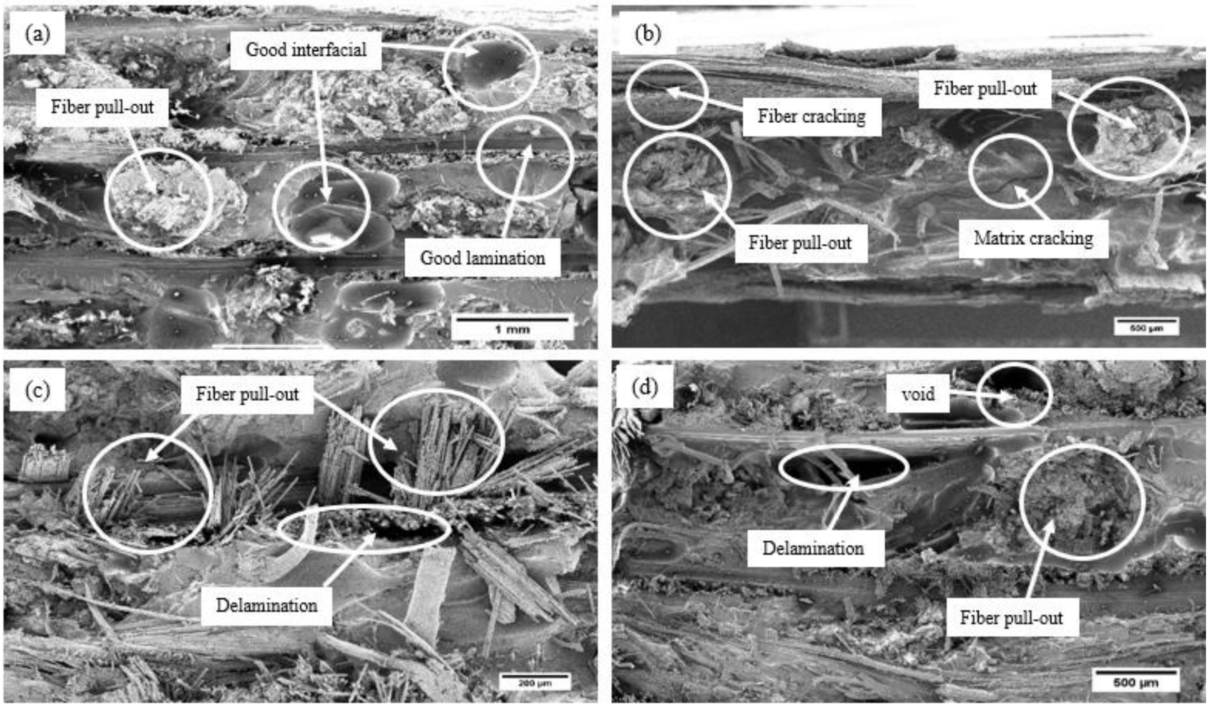
Appendix 2: Lamination of CKCKC hybrid composites at (a) 30 vol.%, (b) 40 vol.%, and (c) 50 vol.% fiber loadings



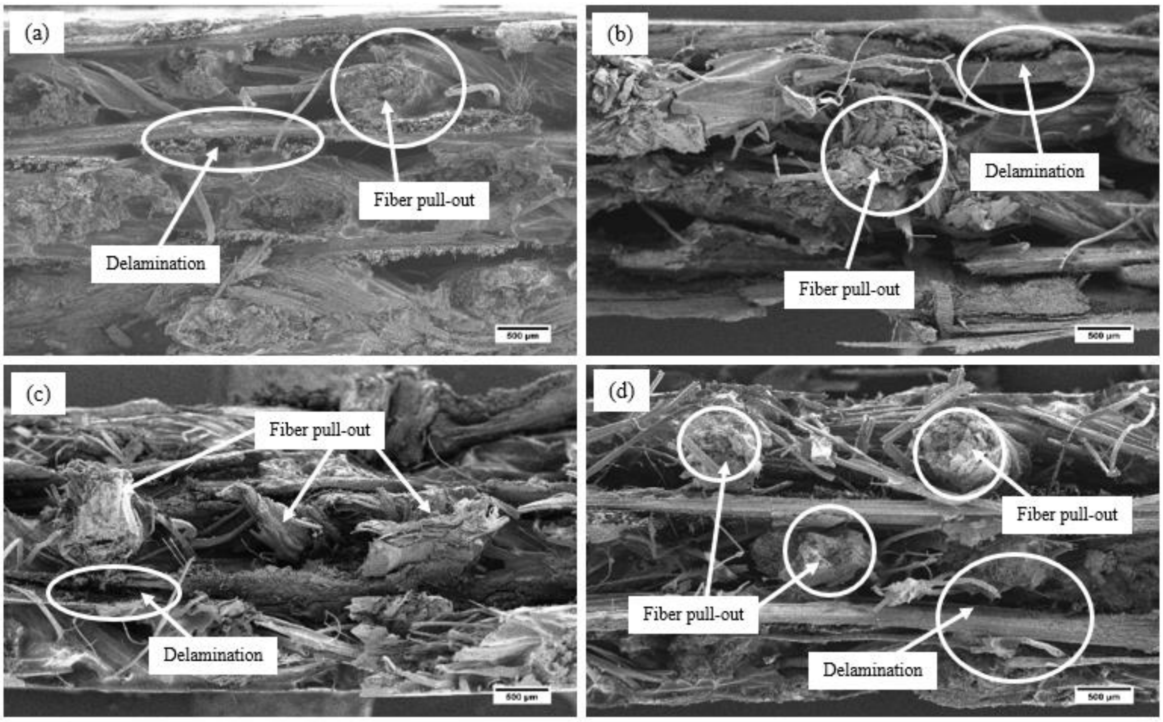
Appendix 3(i) : Tensile fracture surface of 30 vol.% carbon-kenaf hybrid composites with (a) CKCKC, (b) CCKCC, (c) CKCK, and (d) KCKCK stacking sequences at ×25 magnification



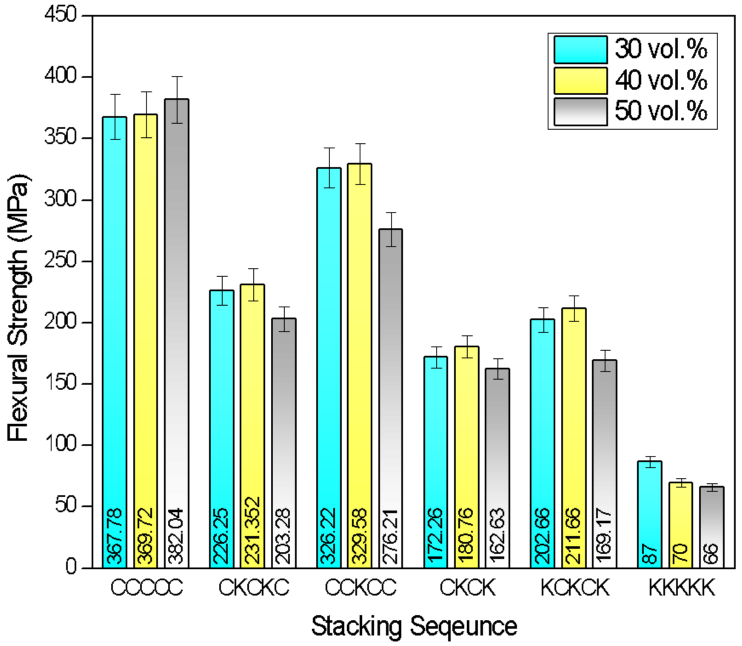
Appendix 3(ii): Tensile fracture surface of 40 vol.% carbon-kenaf hybrid composites with (a) CKCKC, (b) CCKCC, (c) CKCK, and (d) KCKCK stacking sequences at ×25 magnification

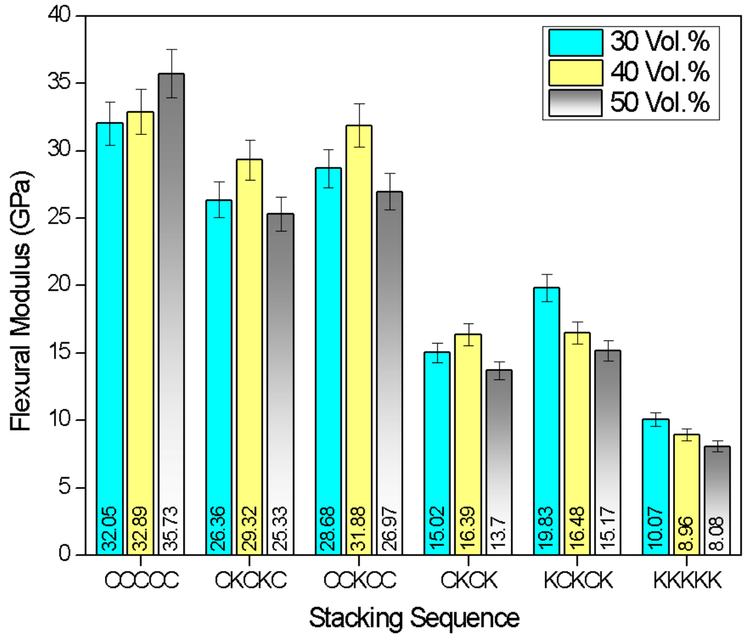


Appendix 3 (iii): Tensile fracture surface of 50 vol.% carbon-kenaf hybrid composites with (a) CKCKC, (b) CCKCC, (c) CKCK, and (d) KCKCK stacking sequences at ×25 magnification

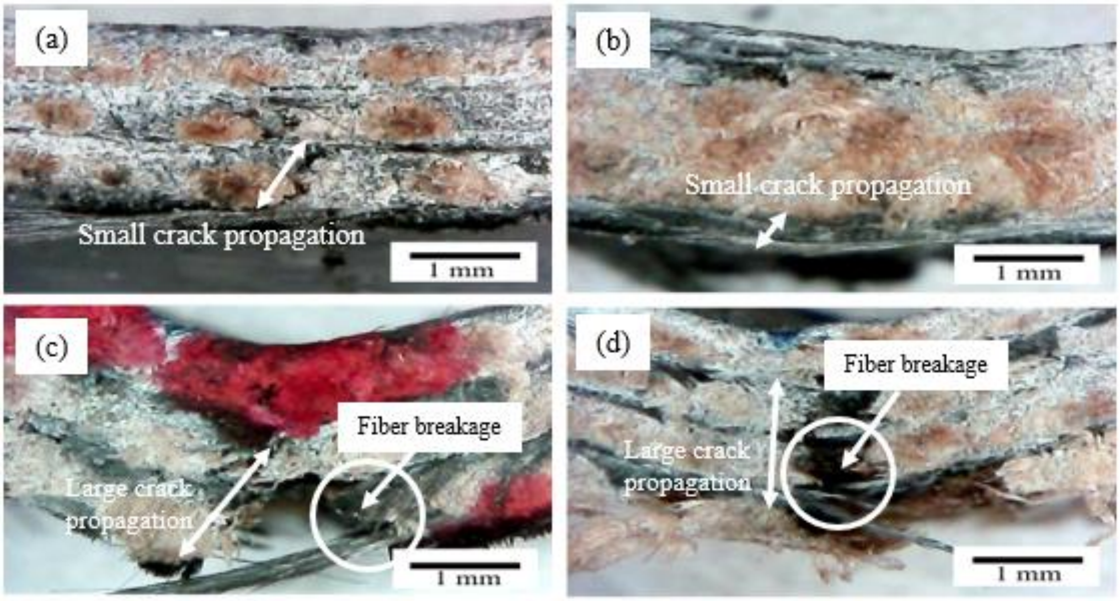


Appendix 4: Flexural strength and modulus of fabricated carbon-kenaf hybrid composites at various fiber content and stacking sequences.

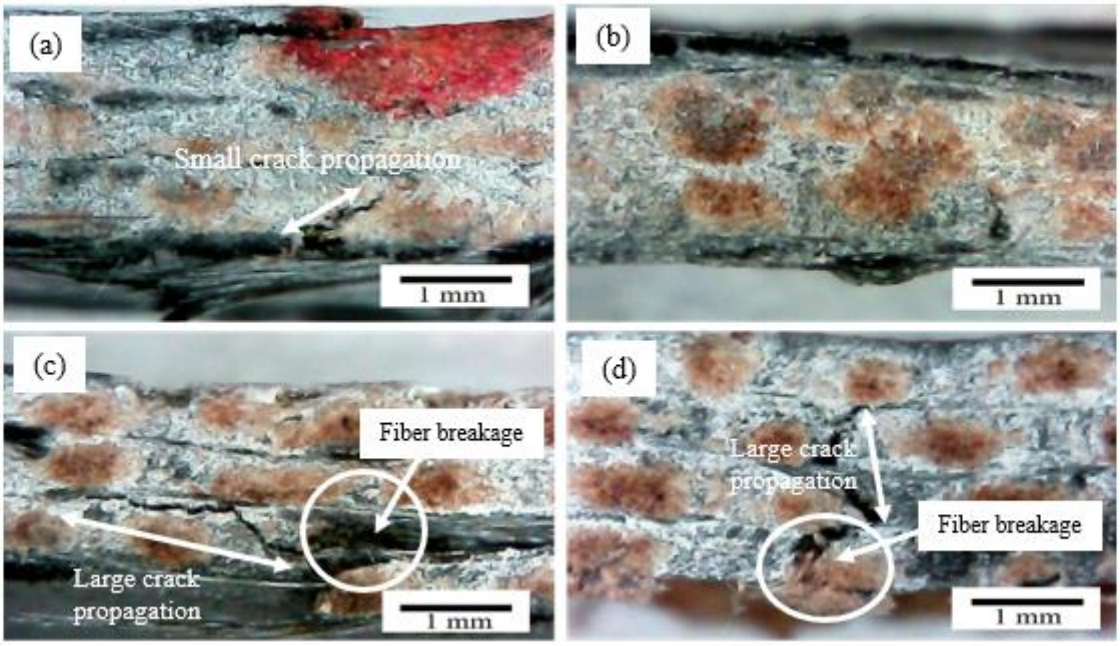




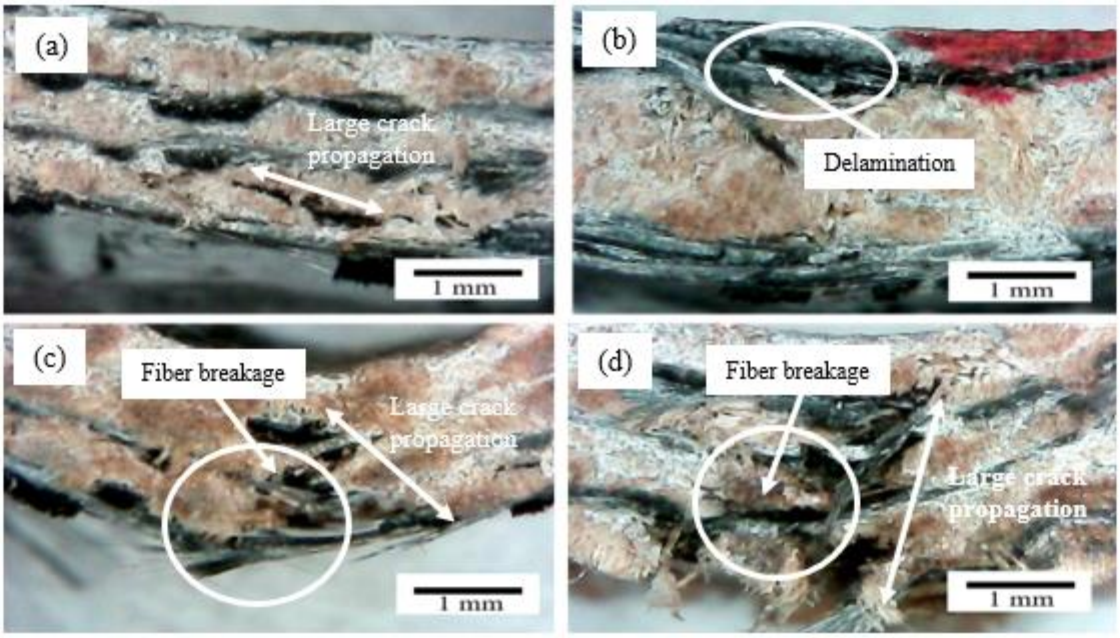
Appendix 5(i): Modes of failure of 30 vol.% carbon-kenaf hybrid composites with stacking sequences (a) CKCKC, (b) CCKCC, (c) CKCK, and (d) KCKCK subjected to flexural testing



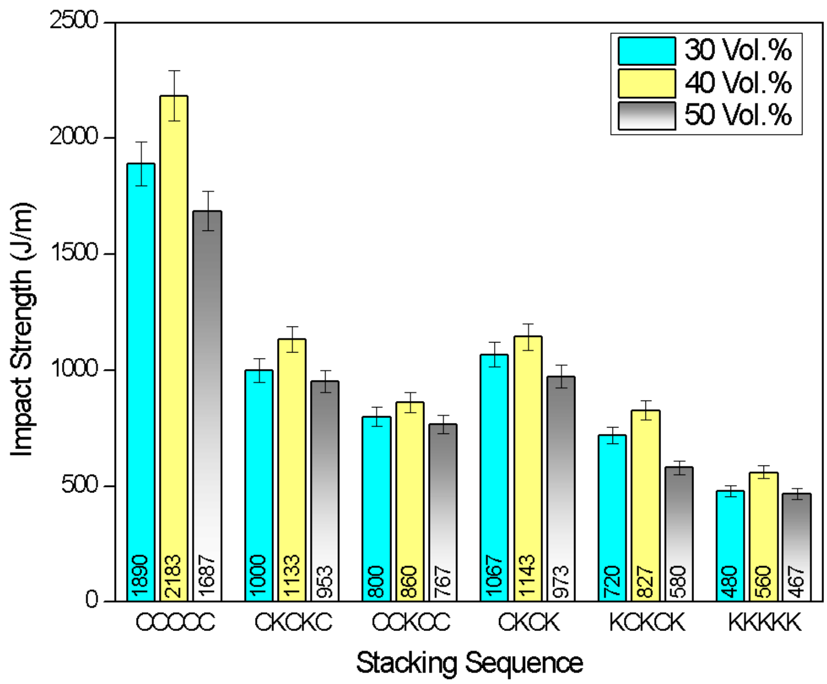
Appendix 5 (ii): Modes of failure of 40 vol.% carbon-kenaf hybrid composites with stacking sequences (a) CKCKC, (b) CCKCC, (c) CKCK, and (d) KCKCK subjected to flexural testing



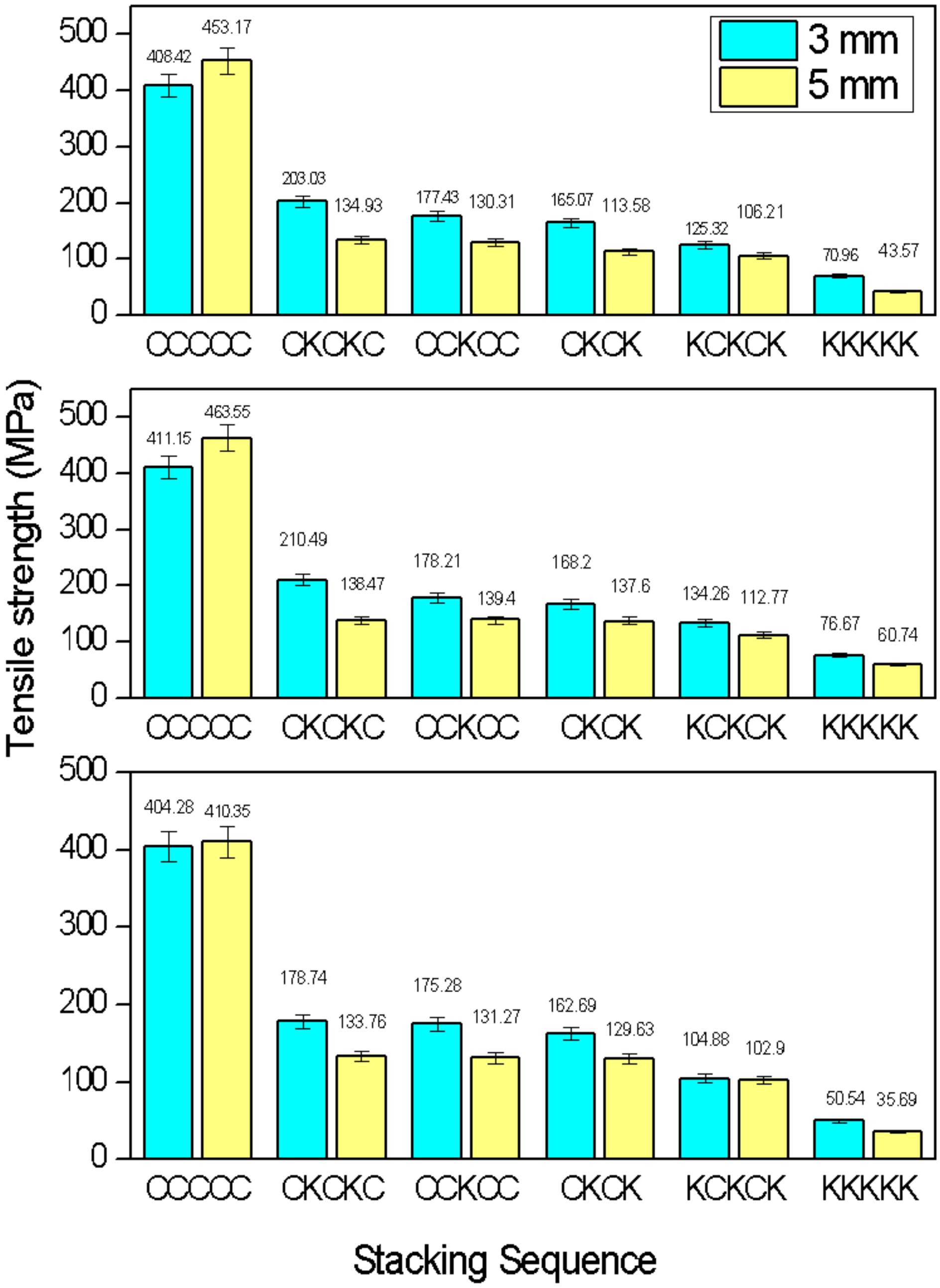
Appendix 5(iii): Modes of failure of 50 vol.% carbon-kenaf hybrid composites with stacking sequences (a) CKCKC, (b) CCKCC, (c) CKCK, and (d) KCKCK subjected to flexural testing



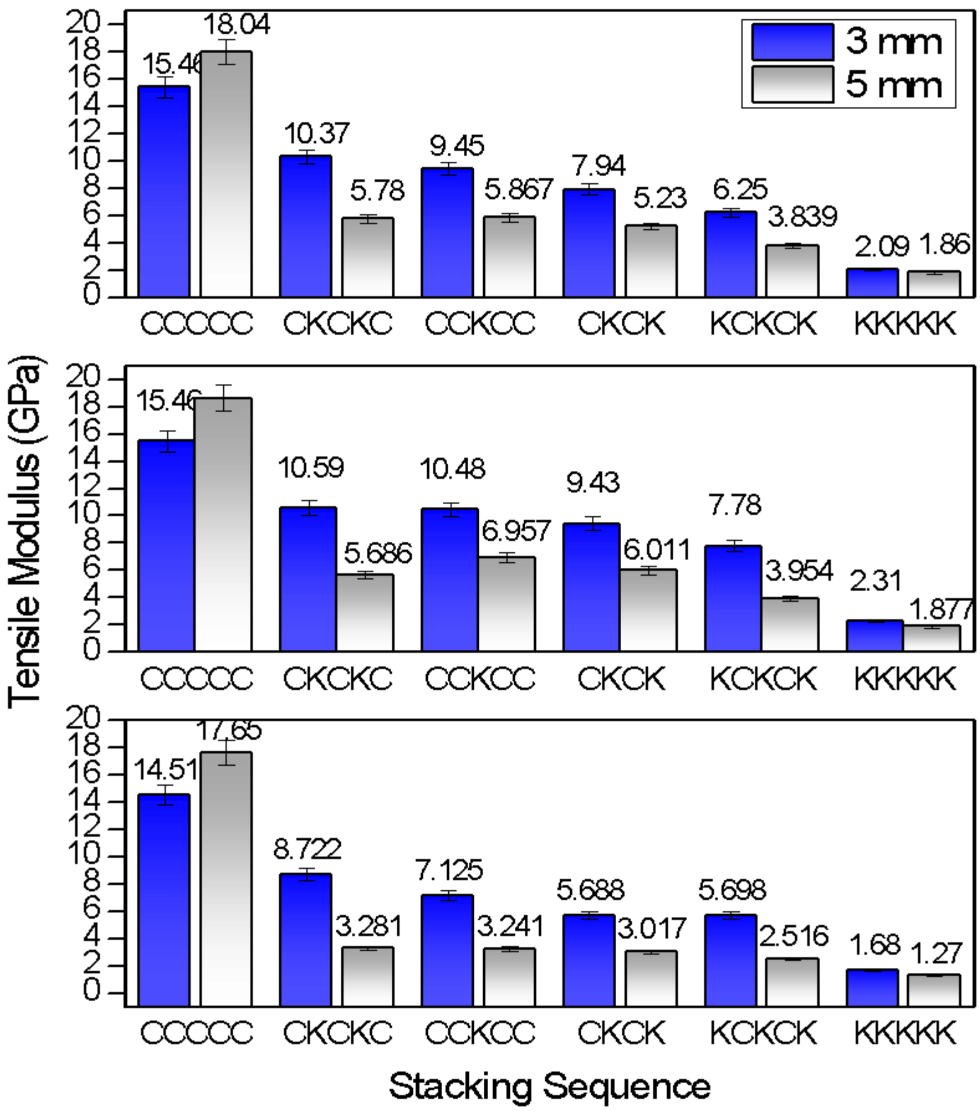
Appendix 6: Impact strength of fabricated hybrid composites at different fiber loadings and stacking sequences



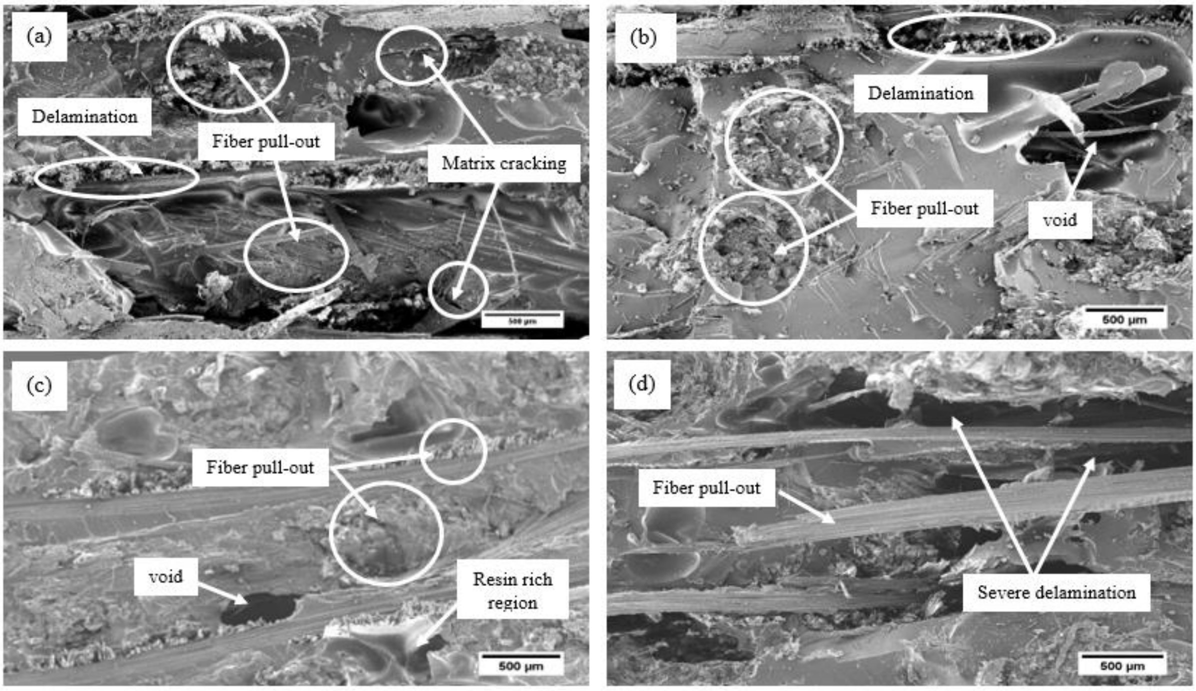
Appendix 7: Tensile strength of carbon-kenaf hybrid composite (a) 30 vol.%, (b) 40 vol.%, and (c) 50 vol.% fiber loadings at 3 mm and 5 mm thickness



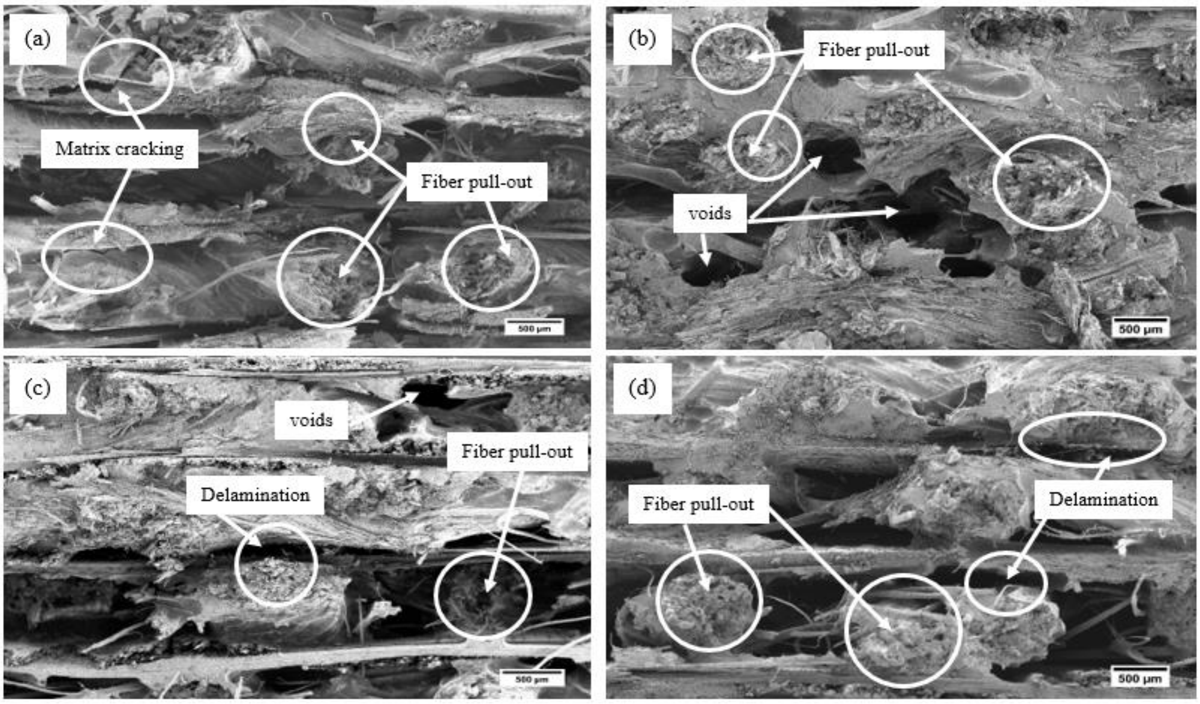
Appendix 8: Tensile modulus of carbon-kenaf hybrid composite (a) 30 vol.%, (b) 40 vol.%, and (c) 50 vol.% fiber loadings at 3 mm and 5 mm thickness



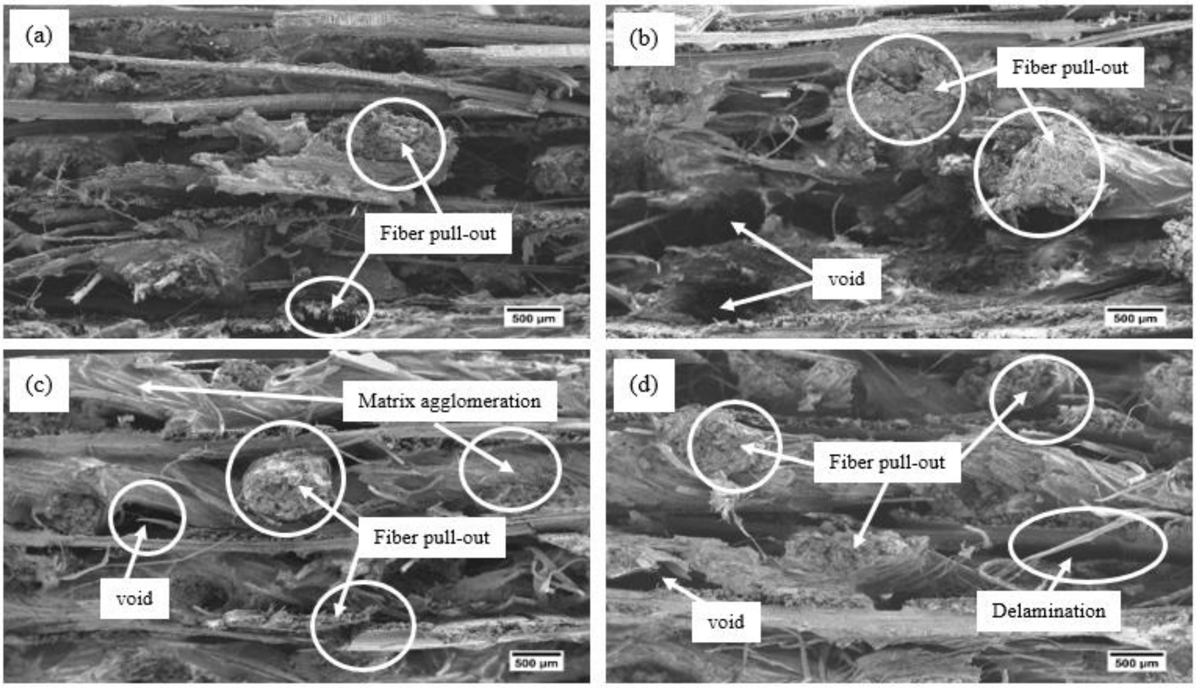
Appendix 9 (i): Tensile fracture surface morphology of 30 vol.% carbon-kenaf hybrid composites with 5 mm thickness and stacking sequence of (a) CKCKC, (b) CCKCC, (c) CKCK, and (d) KCKCK at ×25 magnification



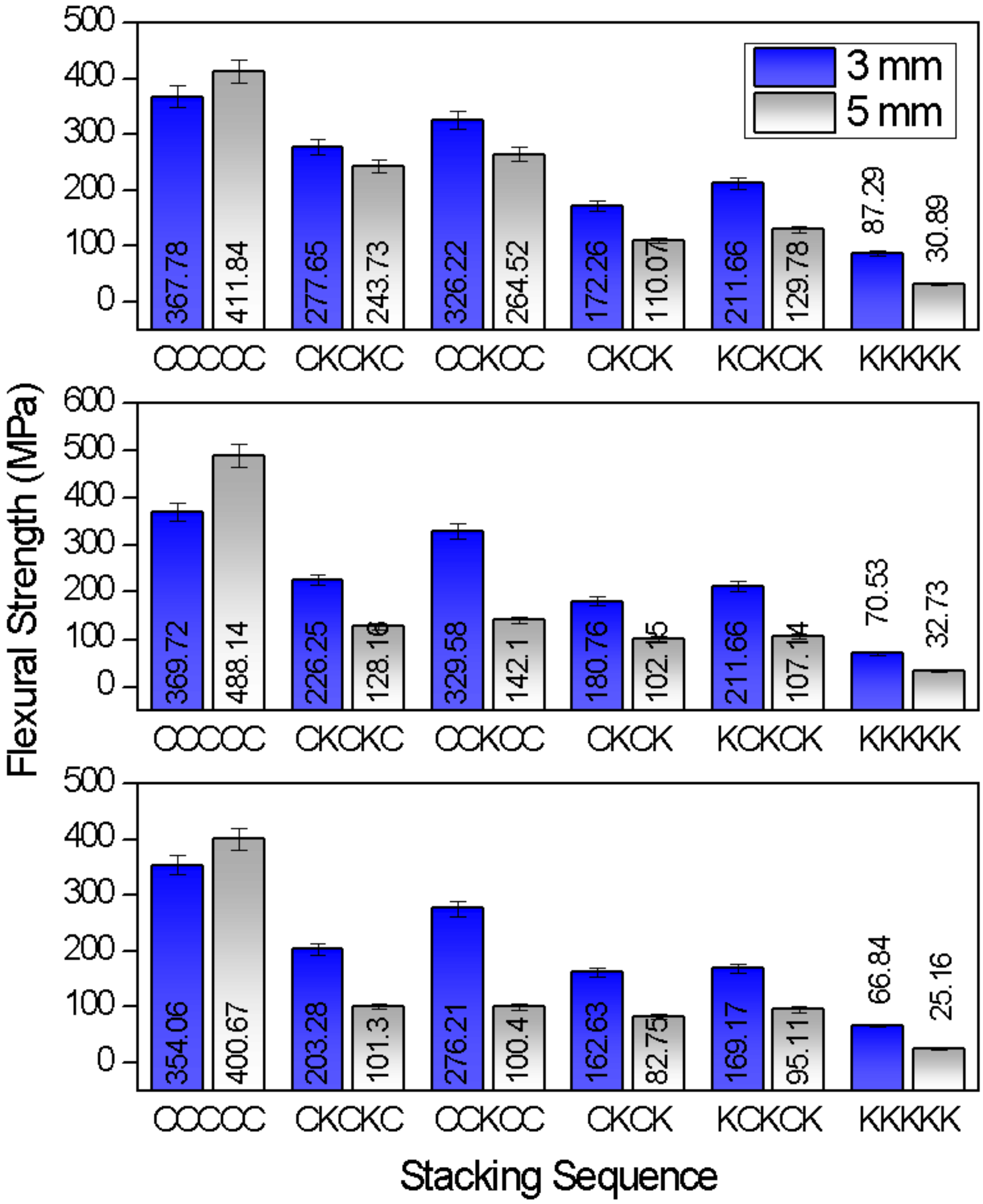
Appendix 9 (ii): Tensile fracture surface morphology of 40 vol.% carbon-kenaf hybrid composites with 5 mm thickness and stacking sequence of (a) CKCKC, (b) CCKCC, (c) CKCK, and (d) KCKCK at ×25 magnification



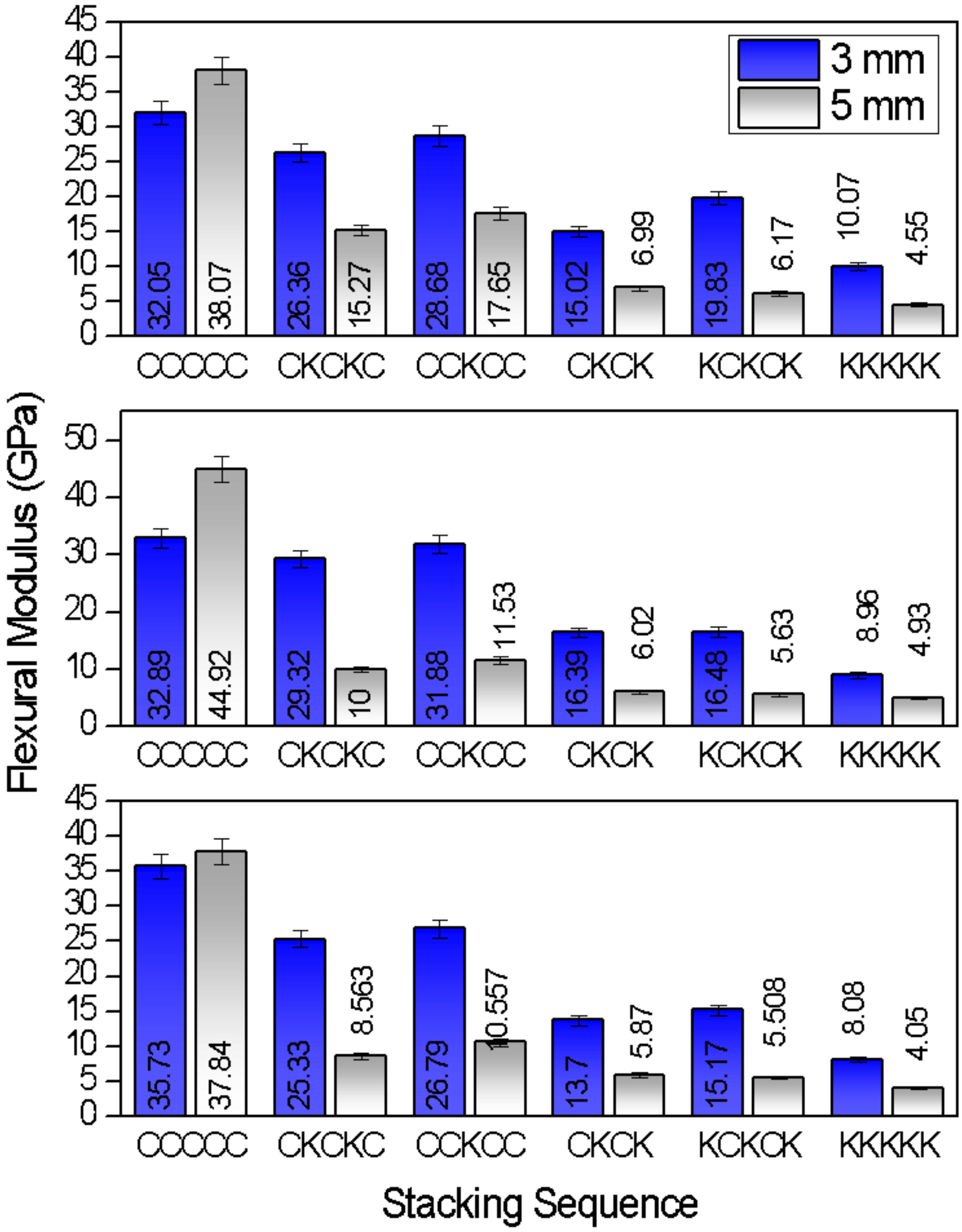
Appendix 9 (iii): Tensile fracture surface morphology of 50 vol.% carbon-kenaf hybrid composites with 5 mm thickness and stacking sequence of (a) CKCKC, (b) CCKCC, (c) CKCK, and (d) KCKCK at ×25 magnification



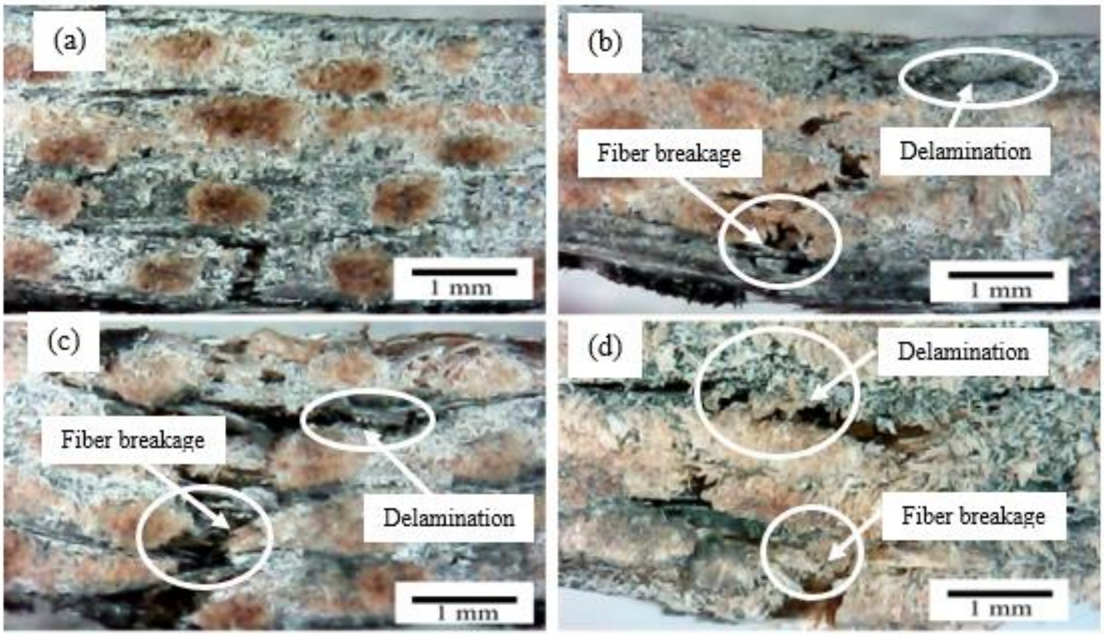
Appendix 10 (i): Flexural strength of (a) 30 vol.%, (b) 40 vol.%, and (c) 50 vol.% fiber hybrid composites at 3 mm and 5 mm thickness



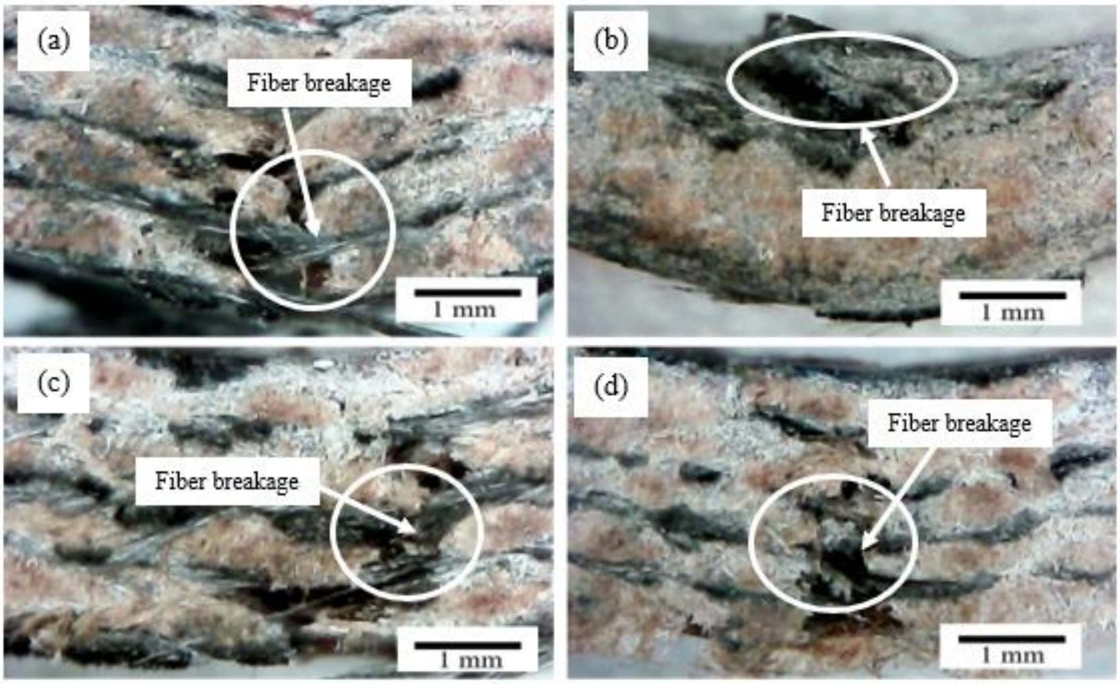
Appendix 10 (ii): Flexural modulus of (a) 30 vol.%, (b) 40 vol.%, and (c) 50 vol.% fiber hybrid composites at 3 mm and 5 mm thickness



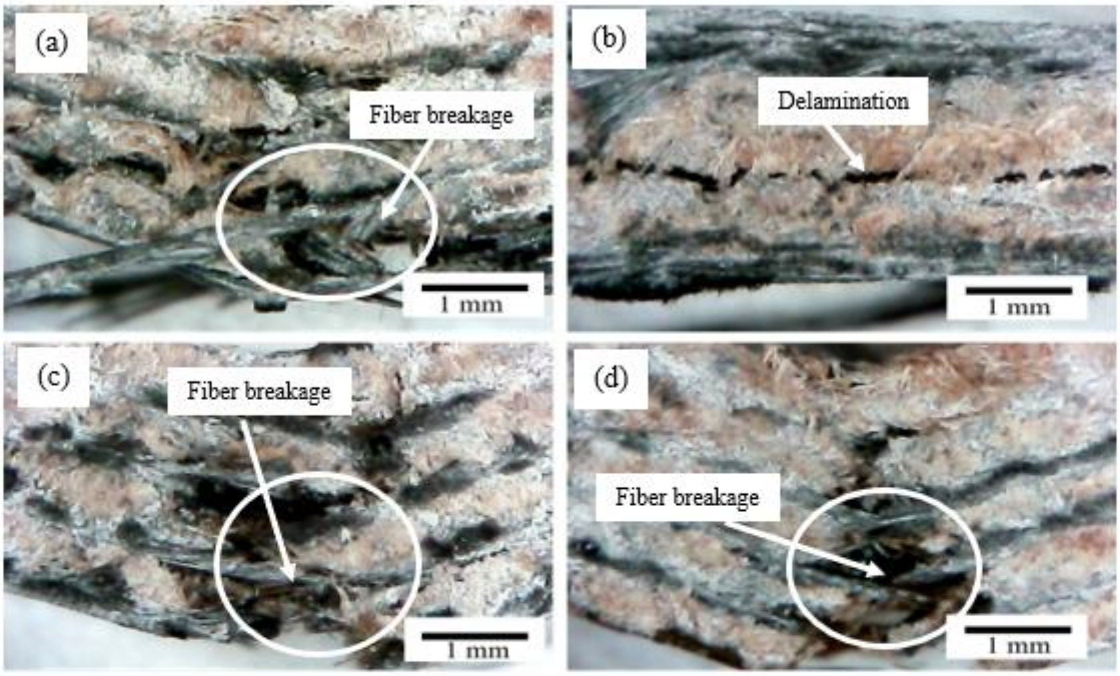
Appendix 11 (i): Flexural modes of failures of 5 mm carbon-kenaf hybrid composites at 30 vol.% fiber loadings with stacking sequence of (a) CKCKC, (b) CCKCC, (c) CKCK, and (d) KCKCK



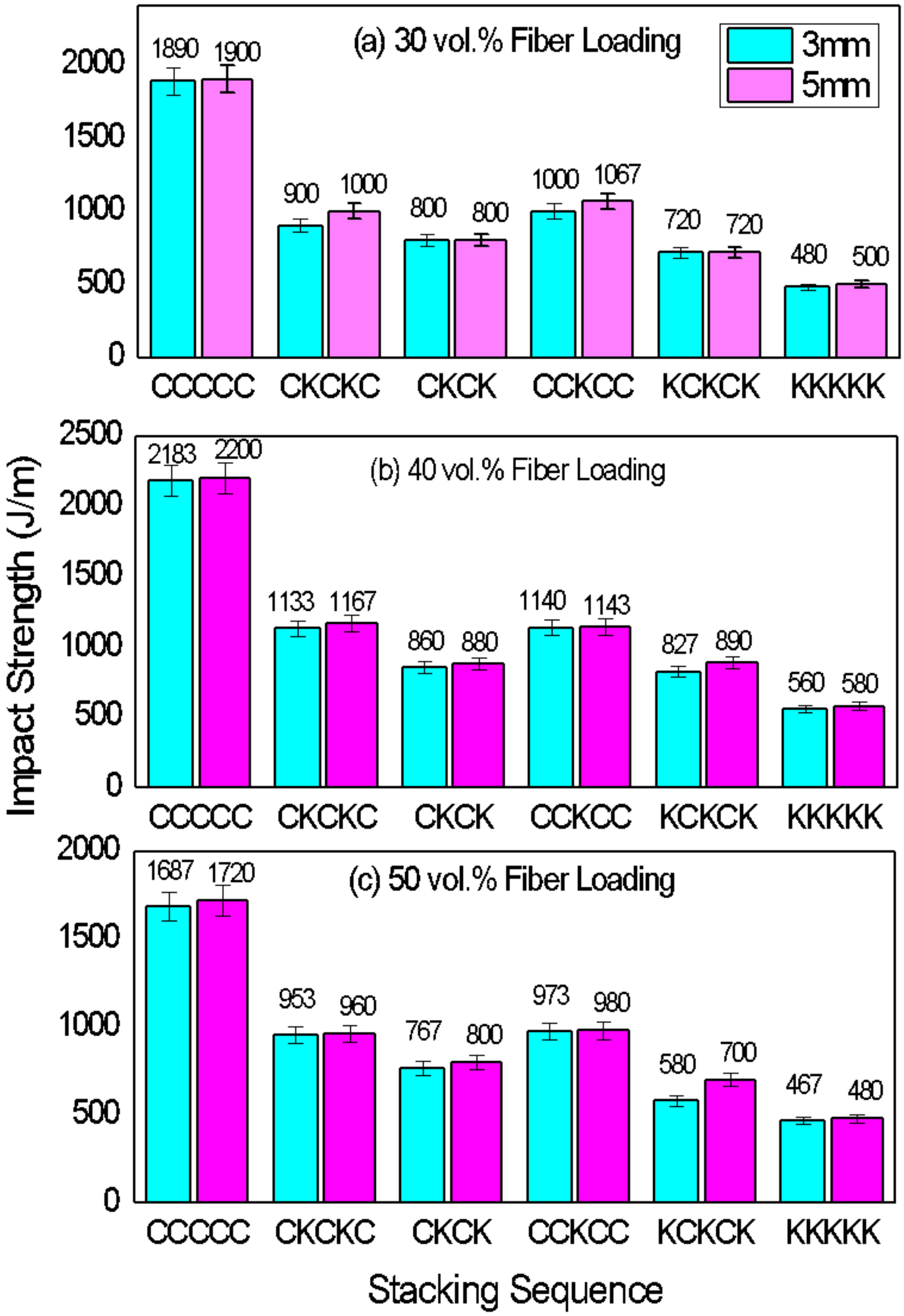
Appendix 11 (ii): Flexural modes of failures of 5 mm carbon-kenaf hybrid composites at 40 vol.% fiber loadings with stacking sequence of (a) CKCKC, (b) CCKCC, (c) CKCK, and (d) KCKCK



Appendix 11 (iii): Flexural modes of failures of 5 mm carbon-kenaf hybrid composites at 50 vol.% fiber loadings with stacking sequence of (a) CKCKC, (b) CCKCC, (c) CKCK, and (d) KCKCK



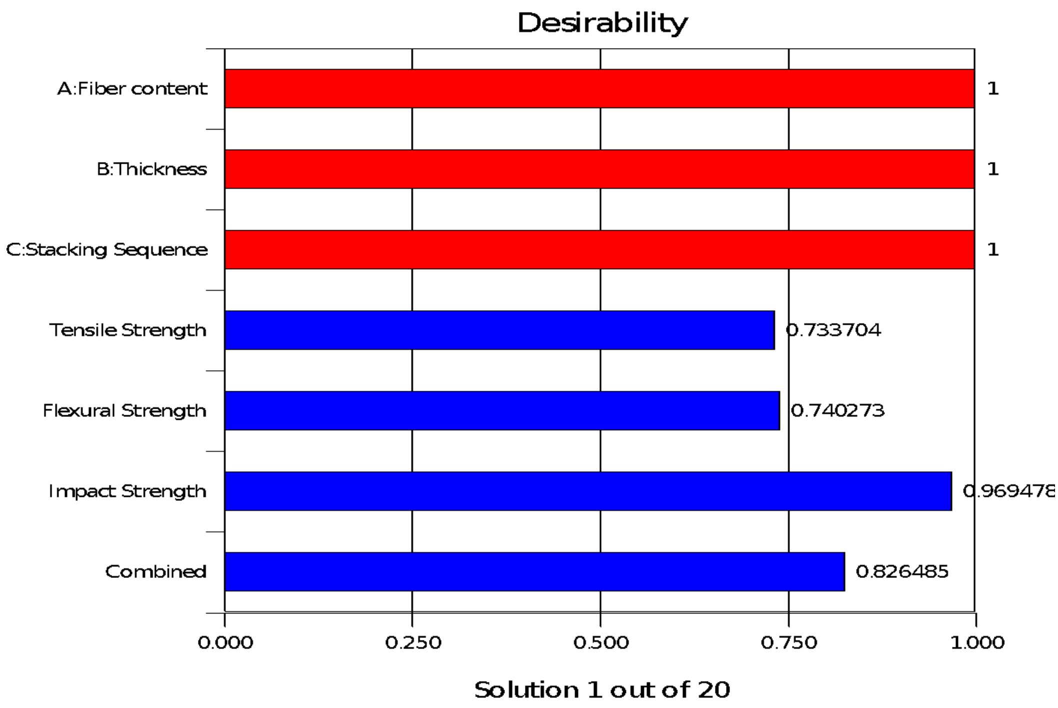
Appendix 12: Impact strength of (a) 30 vol.%, (b) 40 vol.%, and (c) 50 vol.% carbon-kenaf hybrid composite at 3mm and 5mm thickness



Appendix 13: Solutions for 24 combinations of three factors with the desirability value

No	Fiber content	Thickness	Stacking Sequence	Tensile Strength	Flexural Strength	Impact Strength	Desirability	
1	**40**	**3**	**3**	**181.839**	**265.472**	**1149.083**	**0.826**	**Selected**
2	40	3	4	193.093	241.247	1117.083	0.796	
3	30	3	3	173.899	302.858	1020.208	0.769	
4	30	3	4	185.153	278.633	988.208	0.744	
5	50	3	3	169.308	221.622	983.208	0.626	
6	50	3	4	180.561	197.397	951.208	0.590	
7	40	5	3	142.442	180.654	1149.083	0.565	
8	30	5	3	134.502	218.040	1020.208	0.534	
9	40	5	4	153.695	156.429	1117.083	0.534	
10	30	5	4	145.755	193.815	988.208	0.523	
11	40	3	2	172.651	179.667	916.083	0.521	
12	30	3	2	164.711	217.053	787.208	0.461	
13	40	3	1	140.912	197.150	837.750	0.423	
14	50	5	3	129.910	136.804	983.208	0.365	
15	30	3	1	132.972	234.536	708.875	0.329	
16	50	5	4	141.164	112.579	951.208	0.315	
17	50	3	2	160.120	135.817	750.208	0.305	
18	30	5	2	125.313	132.235	787.208	0.256	
19	50	3	1	128.381	153.300	671.875	0.212	
20	40	5	2	133.253	94.849	916.083	0.211	

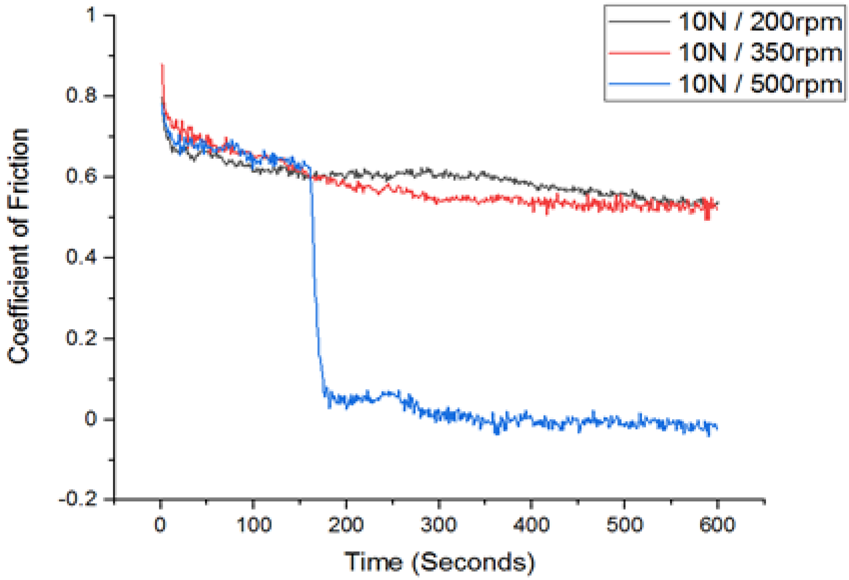
Appendix 14: Desirability value of factors and responses for the selected carbon-kenaf hybrid composite



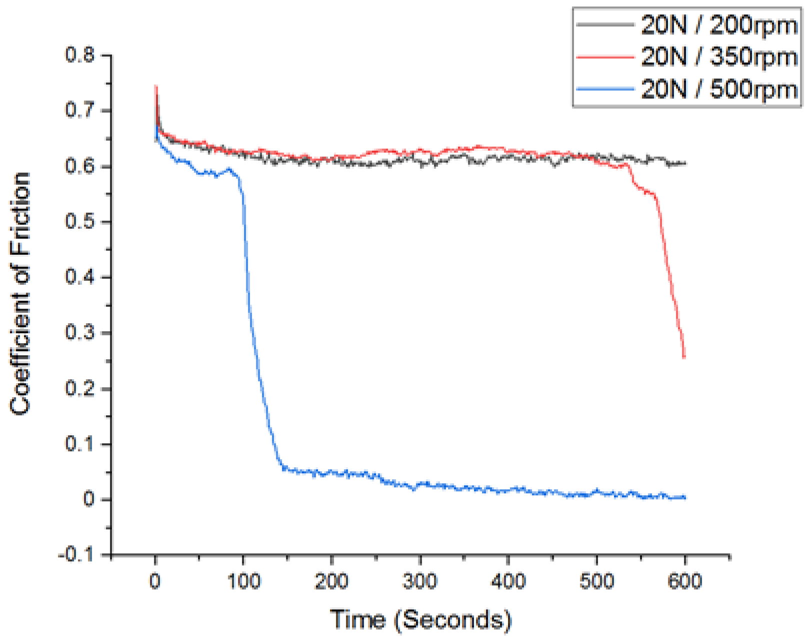
Appendix 15: Summary and comparison of predicted vs experimental results

Method	Reponses	Optimal conditions	Predicted values	Experimental values
Multi-response optimization	Tensile strength Flexural Strength Impact strength	Factor A (40 vol.%) Factor B (3mm) Factor C (Type 3 – CCKCC)	181.839 MPa 265.472 MPa 1149.08 J/mm	**202.72 MPa** **299.31 MPa** **1150 J/mm**

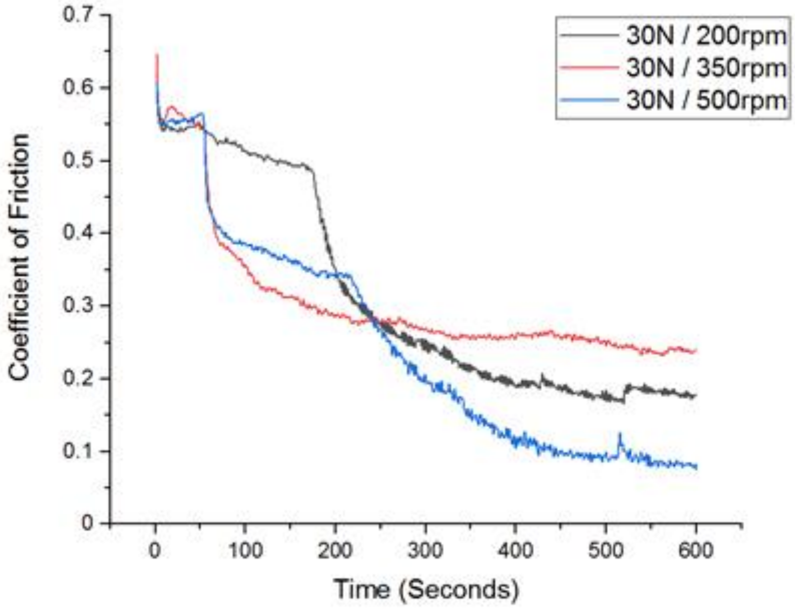
Appendix 16: Coefficient of friction for CCKCC hybrid composite with constant load 10N and different speeds



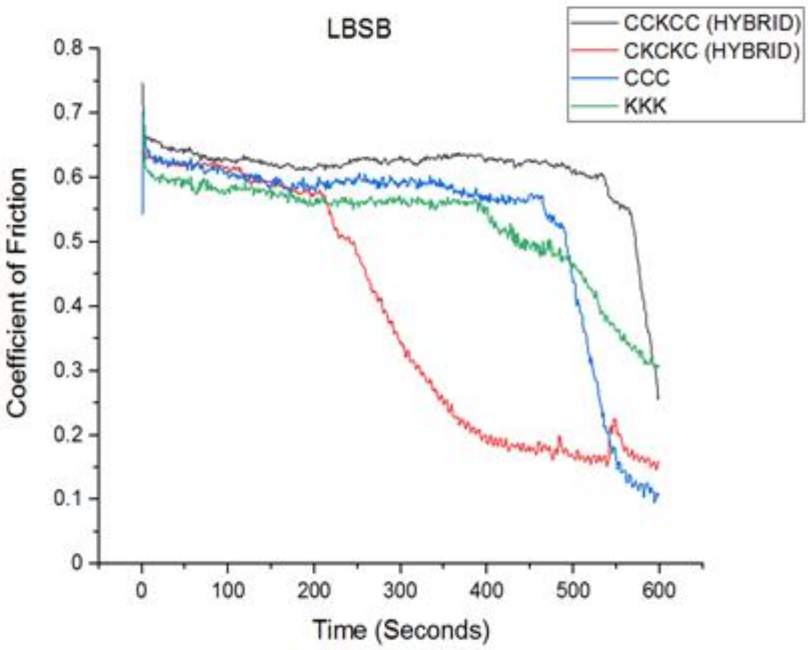
Appendix 17: Coefficient of friction for CCKCC hybrid composite with constant load 20N and different speeds



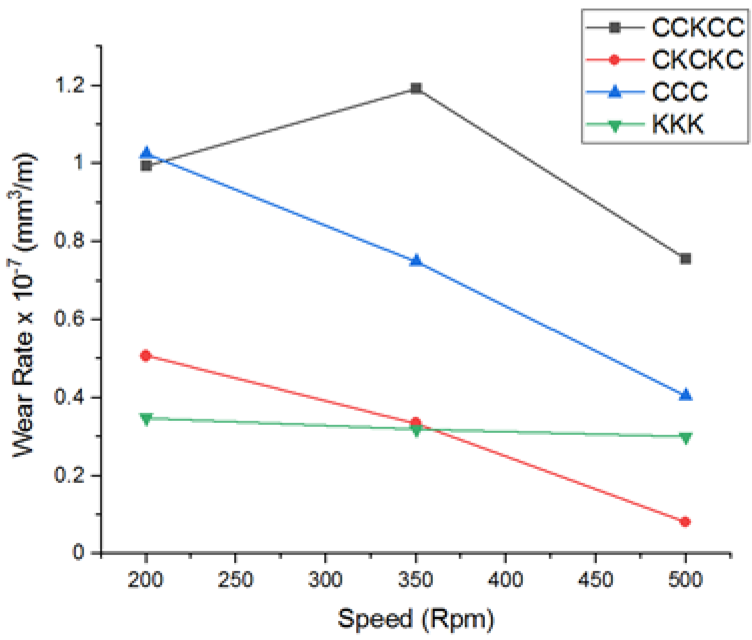
Appendix 18: Coefficient of friction for CCKCC hybrid composite with constant load 30N and different speeds



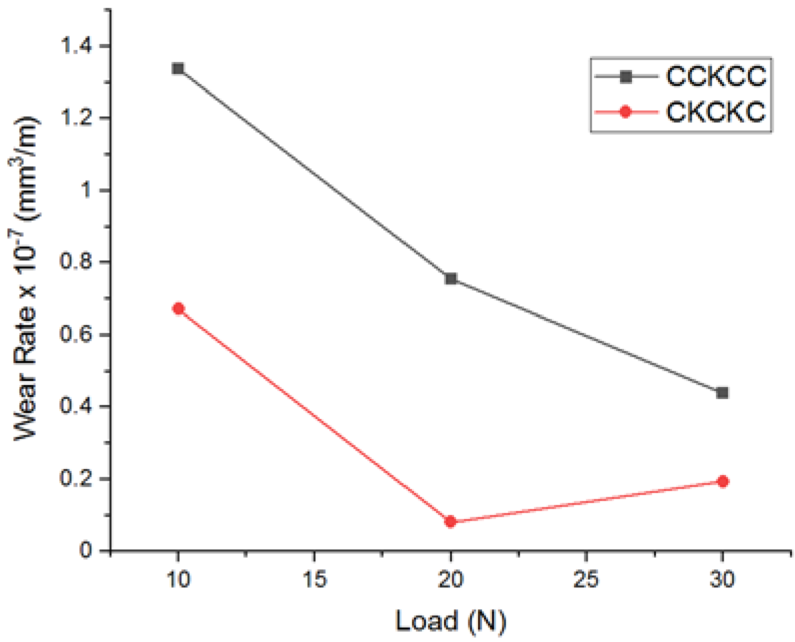
Appendix 19: Coefficient of friction for CCKCC, CKCKC, CCC and KKK hybrid composites sliding at load (30N) and speed (350 rpm)



Appendix 20: Wear rate vs speed at constant load 20 N

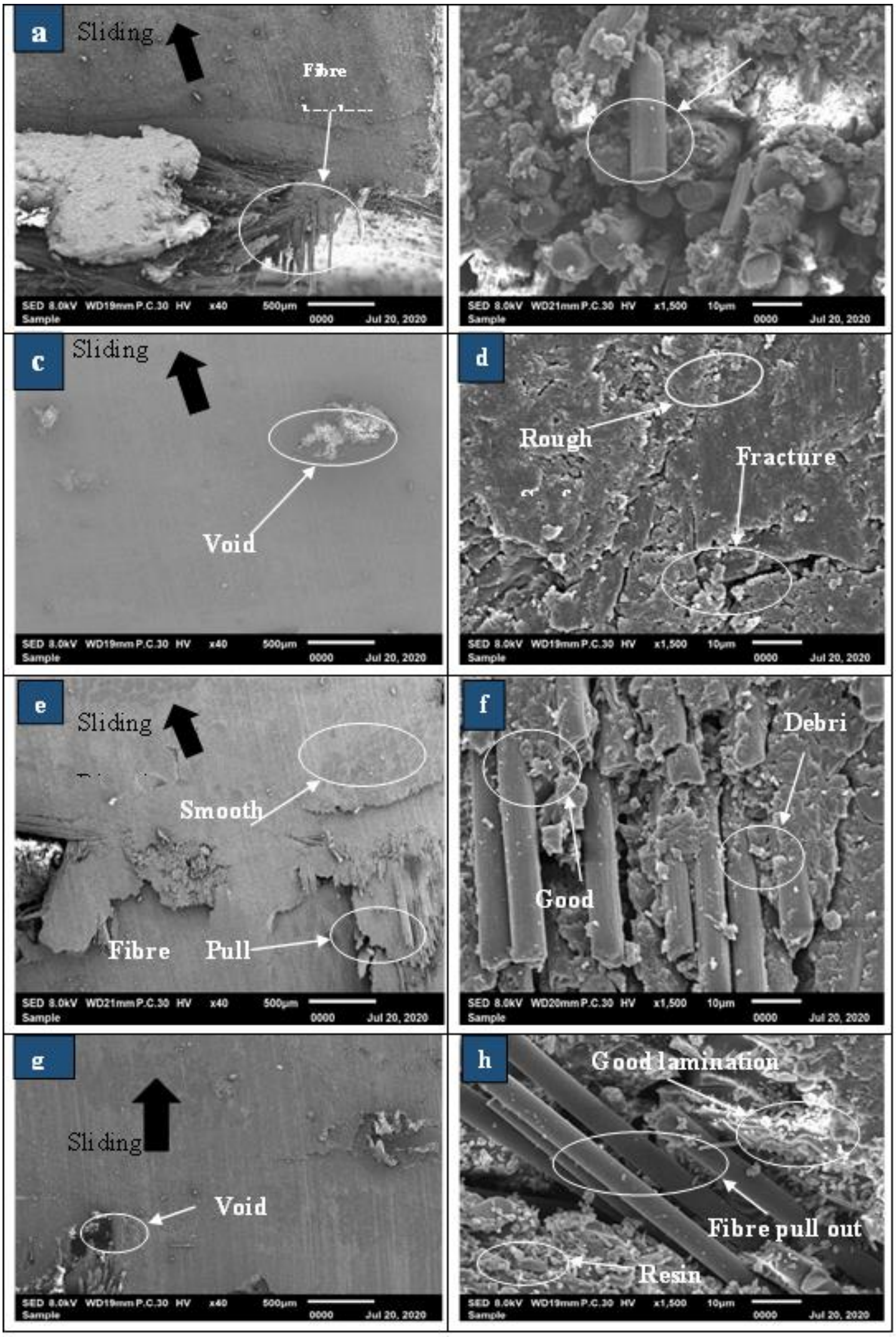


Appendix 21: Wear rate vs load at constant speed 500 rpm



Appendix 22: Morphology of hybrid composites (a) CCKCC 200rpm/20N X40 (b) CCKCC 200rpm/20N X1500 (c) CCKCC 350rpm/20N X40 (d) CCKCC 350rpm/20N X1500 (e)

CKCKC 200rpm/20N X40 (f) CKCKC 200rpm/20N X1500 (g) CKCKC 350rpm/20N X40 (h) CKCKC 350rpm/20N X1500



Appendix 22:Micrograph of hybrid composites (a) CCKCC 200rpm/20N (b) CCKCC 200rpm/30N (c) CCKCC 350rpm/20N (d) CCKCC 500rpm/20N (e) CKCKC 350rpm/20N (f) CKCKC 500rpm/20N (g) CCC 350rpm/20N (h) KKK 350rpm/20N