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Original Article

Effects of layering sequence and gamma radiation on mechanical properties and morphology of Kevlar/oil palm EFB/epoxy hybrid composites

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ABSTRACT

The present study evaluates the tensile and flexural properties, including the morphological features of gamma radiated Kevlar/oil palm empty fruit bunch (EFB)/epoxy hybrid composites fabricated using hand lay-up method with different layering sequences. The fabricated hybrid composites were exposed to different gamma radiation doses: 25 kGy, 50 kGy and 150 kGy. Mechanical (tensile and flexural) and morphological properties were evaluated by using universal testing machine and scanning electron microscopy, respectively. Results obtained indicated that tensile strength of hybrid composites were effected by layering sequence. The layering sequence involving the use of EFB as core material yielded better mechanical performance compared to the layering pattern when Kevlar served as the core material. The tensile and flexural properties of hybrid composites showed an improvement for irradiated samples at a low radiation level. Hybrid composites displayed decrease in tensile strength at 50 kGy whereas flexural strength still showed an improvement. However, at 150 kGy, the tensile and flexural properties exhibited significant degradation. FESEM of tensile fracture composites showed the exist of fibre pull out and voids. However, at 150 kV bigger and ruptured voids were observed. It can be concluded from this finding that mechanical performance of Kevlar/EFB/Kevlar hybrid composites after Gamma radiation, has made it as promising material for automotive, aerospace and construction applications.

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1. Introduction

Oil palm is widely cultivated in Southeastern Asia namely in countries such as Malaysia, Indonesia, Thailand etc. However, its plantation is generating abundant wastes. The accumulation of wastes and the excessive use of synthetic materials have raised major environmental concern. Hence, in recent years, many researches have focused on developing eco-friendly materials in order to reduce the usage of synthetic materials [1,2]. Oil palm EFB natural fibre are waste from palm oil industry. Malaysia, as the world second largest exporter of palm oil after Indonesia, by being in this situation, has generated an abundance of waste from the industry due to being under-utilized. This scenario raise environmental concern and problems in replanting operations. It is reported that in the year 2017, the palm oil plantation area in Peninsular Malaysia was accounted for 2.71 million hectares or 46.6% of the total planted area. Sabah is the highest plantation area covering 89.1% of the total oil palm planted area in the state. Sarawak recorded a total matured area of 86.3% [3]. In overcoming the environmental issues, many efforts have been done to overcome the problems such as turning the oil palm industry waste to food packaging materials [4], briquette [5], composites [6] and as the fuel for biomass energy production [7]. The oil palm EFB has gain interest to the researches in producing composites made from the oil palm EFB [8,9].

The possibility of preparing hybrid composites combining natural fibres, such as those obtained from oil palm wastes with synthetic ones, has been intensively investigated [10–12]. The mechanical properties [13,14] and impact performance [15–17] of synthetic composites have been investigated. Natural fibre-based hybrid composites are currently receiving great attention as a material with better mechanical [18–21] and impact properties [22,23]. Recently, Salman [24] studied the effects of fibre orientation on the mechanical properties and morphology of woven-kenaf/polyvinyl butyral films. Patil et al [25] studied on the hybrid between Kevlar and Jute. Hybrid of natural fibre, ramie with Kevlar-polyester composites were also studied by Radif et al. [26]. Tension-compression fatigue behaviour of plain woven kenaf/Kevlar hybrid composites has also been studies [27].

Some studies have reported on the development of hybrid composites based on oil palm fibres, combined with a variety of other fibres, including natural ones, for instance coir and jute, and synthetic fibers, for examples glass, Kevlar, and carbon fibres, are tabulated in Table 1.

Improving the mechanical strength of a material is essential in achieving its desirable performance for specific applications. Besides fiber hybridization, there are a number of methods to enhance the mechanical properties of the composites, such as physical and chemical treatments and exposure to radiation. Irradiation techniques, involving gamma rays or electron beam, are regarded as efficient methods in improving the mechanical properties of polymer composites [30]. Zaman et al. [31] investigated the mechanical and electrical properties of gamma radiated jute fabric/polymer composites. They observed that, upon irradiation, the tensile and bending properties increased with a rising radiation level from 250 to 500 krad, while further increasing the radiation level up to 1000 krad, led to a decrement of the examined properties. The study on the gamma radiation effect towards the mechanical properties of pineapple leaf fibre (PALF)/jute fibre polymer composites has been conducted [32]. The researchers applied a lower radiation dose during the tests and realized that at 5 kGy the highest tensile and flexural values were achieved, while increasing the radiation dose decreased the tensile values. The high energy gamma radiation effect on aramid fiber-12 has been studied and it was revealed that gamma radiation enhances the interphase properties between epoxy and fiber besides this also improved the interfacial strength of single fibre composites [33].

The present work aimed to develop gamma irradiated Kevlar/oil palm EFB/epoxy composites and investigate their tensile and flexural properties, including the morphological characteristics of tensile fractured specimens. The findings of this study will open a new platform to fully utilize the usage of natural fibres by hybridizing them with synthetic fibres together with the effect of gamma radiation to achieve an improved mechanical strength.

2. Materials and methods

2.1. *Materials*

In this study, oil palm EFB, in the form of compressed fibre mats, and woven Kevlar fabric were used. The supply of Kevlar in woven fabric was done by ZKK Sdn. Bhd. Malaysia while the oil palm EFB was purchased from HK Kitaran Sdn. Bhd. Malaysia. Also, epoxy resin (Zeepoxy HL002TA) and its corresponding hardener (Zeepoxy HL002TB) were both supplied by ZKK Sdn. Bhd. Malaysia.

2.2. *Composites fabrication*

In this study, fabrication of all the composites were done with hand lay-up method using a mould made from carbon steel with the dimensions of 300 mm x 200 mm. The releasing agent used were glazing wax and were applied to the cavity of the mould. The composites were layered accordingly with the epoxy resin in the mould. The mould was closed and pressed using the lid for removing the excess resin. The curing process took 24 h at room temperature. After removing the mould, the post curing process took place in an oven for 3 h at 80 °C, with the objective of ensuring that the resin was completely dried. The hybrid composites were fabricated with two different layering pattern as illustrated in Fig. 1. The first layering pattern of the composites consist of layering together the oil palm EFB fibre mat and the woven Kevlar fabric, which the oil palm EFB fibre acts as the core and the Kevlar fabric as the skin (K/OP/K). In the second layering pattern the Kevlar fabric was layered in between the layers of oil palm EFB fibre (OP/K/OP).

2.3. *Gamma irradiation of samples*

Before the irradiation process, the composites were cut into specific dimensions. The samples were irradiated in Malaysian Nuclear Agency, Malaysia, at the SINAGAMA radiation facility

Table 1 – Studies on mechanical properties of oil palm based hybrid composites.

Oil palm based hybrid composites	Mechanical properties	References
Oil palm-chopped glass strand	Tensile and Flexural	Tshai et al. [10]
Jute - oil palm	Tensile	Jawaid et al. [28]
Coir - oil palm	Tensile, Flexural and Impact	Zainudin et al. [29]
Oil palm - glass fibres	Flexural	Karina et al. [11]
Oil palm – carbon fibresOil palm – Kevlar fabrics	Tensile	Amir et al. [12]

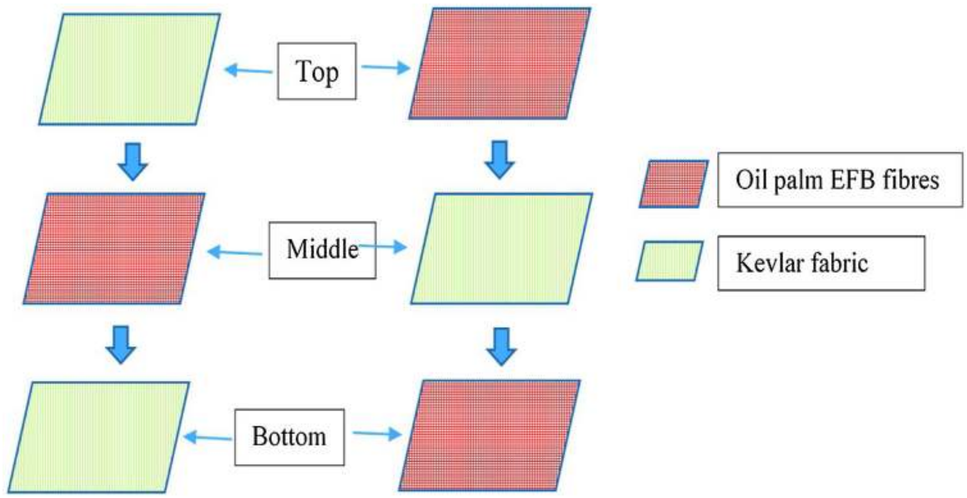

Fig. 1 – Different layering patterns of the fabricated hybrid composites.

Table 2 – Radiation Dose for hybrid composites.

Radiation Doses (kGy)	K/OP/K	OP/K/OP
0 kGy	L 101	L 201
25 kGy	L 102	L 202
50 kGy	L 103	L 203
150 kGy	L 104	L 204

at room temperature and ambient humidity at different doses; 25 kGy, 50 kGy and 150 kGy as shown in Table 2.

In hybridizing this composites, natural fibre and synthetic were used. The radiation dose is in the lower range for natural fibre and the radiation dose is in the higher range for synthetic fibre. In oil palm EFB, the radiation dose chosen starts from 25 kGy. The radiation dose for oil palm EFB in this work were chosen based from the literature [34] where by in the literature, the radiation dose for oil palm EFB taken were 25 kGy and 50 kGy. Radiation dose lower than 25 kGy will not have any changes in the mechanical properties [35]. For Kevlar, the radiation dose chosen starting from 150 kGy. Xing et al. [33] conducted the radiation exposure to aramid fibre with 400 kGy which is higher range of radiation dose. However, in this work, the hybrid composites fabricated comprise of combination between natural and synthetic fibre, hence the higher range of radiation dose chosen in this work starts from 150 kGy which is lower from the previous work [33].

2.4. *Tensile properties*

The tensile test of the hybrid composites were tested according to the ASTM D 3039 specifications. Shimadzu Ag Universal Testing Machine with the capacity of 50 kN was applied in this work. Five replicate specimens were measured and the average value was tabulated. The 2 mm/min of cross-head speed was applied to the composites until the samples were fractured.

2.5. *Flexural properties*

Flexural properties were evaluated by carrying out three-point bending tests as per ASTM D790. The tests were performed at room temperature, using an INSTRON 8874 Universal Testing Machine, with a load of 25 kN, as shown in Fig. 2. For each test, five replicate specimens were measured and the average value was tabulated. The cross-head speed for K/OP/K samples was 3 mm/min, while for OP/K/OP samples was 5 mm/min.

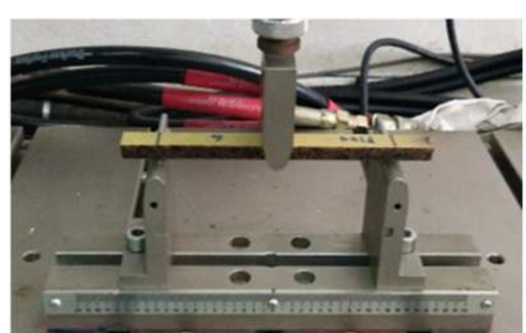

Fig. 2 – Flexural Testing.

2.6. Morphological observation

Morphological images of the tensile fractured hybrid composites were obtained on a LEICA EZ4 HD stereo microscope and on a FESEM instrument made by Carl Zeiss, Model Gemini SEM 500.

2.7. Gel content

The amount of crosslinked by the gamma radiation was determined using the calculation of the crosslinking degree, before and after radiation [36]. The weight of the each sample prepared were 0.2 g and put into the wire mesh. Five replicates specimens were measured and the average value was tabulated. Tetrahydrofuran (THF) was used as the solvent and the samples were left for 24 h in the solvent [36]. After leaving for 24 h, the samples were rinsed with the same solvent once and followed by methanol twice. The samples were dried in the oven for 4 h at temperature 70^{0}C. The degree of crosslinking is calculated using Eq. 1

$$\textit{Degree of crosslinking}\ (\%) = \left(\frac{W_s - W_o}{W_i - W_o}\right) \times 100 \quad (1)$$

where

W_s = mass of the non-soluble sample, after drying, in grams
W_i = initial sample mass in grams
W_o = mass of the wire mesh

2.8. Data analysis

The data were statistically analysed using one-way ANOVA (analysis of variance) using MINITAB 2018 software. The purpose of the analysis is to determine the existence of any statistically significant differences between the means of two or more different laminates. In one-way ANOVA analysis, the variance was decomposed into two categories which were between the groups (BG) and within the groups (WG) [37]. From the analysis, if the P-value of the F-test is less than 0.05, then this rejects the null hypothesis which can be concluded that there is a statistically significance difference with 95% confidence level. From the MINITAB 2018 software, normal probability plot were plotted. The normal probability plots evaluate the goodness of fit of the model in the one-way ANOVA analysis performed [37]. The normal probability plot determines whether the data might by normally distributed. In the normal probability plot, if the resulting data close to the straight line, hence the data are approximately normally distributed. However, the deviations from the normalization line suggest partings from normality.

3. Results and discussion

3.1. Tensile properties

The effect of gamma radiation dose on the tensile strength of Kevlar/oil palm EFB/Kevlar (K/OP/K) and oil palm EFB/Kevlar/oil palm EFB (OP/K/OP) are shown in Fig. 3. It can be clearly observed from Fig. 3 that the K/OP/K (27.7 MPa) showed better tensile strength by about 48.1% than the OP/K/OP layering sequence (18.7 MPa). The hybrid with the layering sequence K/OP/K exhibited better tensile strength because Kevlar, which is used as the skin of the laminate, was in woven form, while the oil palm EFB core represented a fibre mat at random orientation. The tensile strength of Kevlar is 3600 MPa [38] while the tensile strength for oil palm EFB is 248 MPa [39]. Since the tensile strength for Kevlar is higher than oil palm EFB, this contributes to the high tensile strength for K/OP/K. The high tensile strength of K/OP/K demonstrates that a laminate with this layering sequence can withstand higher tensile stress as compared to the OP/K/OP layering.

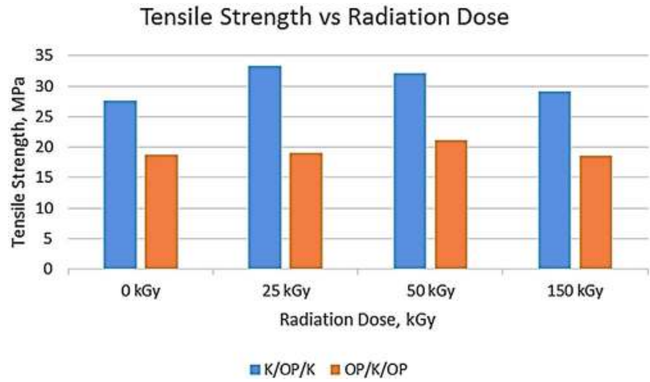

Fig. 3 – Tensile strength of hybrid composites.

Observing the tensile properties of the hybrids, it can be noted that the non-irradiated K/OP/K hybrid has lower tensile strength in comparison with the irradiated K/OP/K hybrid composites. Moreover, the tensile strength for 25 kGy irradiated samples was increased by 20.2%. The results showed an improvement at 25 kGy because small radiation dose below 15 kGy will not cause any significant effect in the mechanical properties [35]. Machnowski et al. [35] concluded that materials irradiated with doses ranges 5–25 kGy will not cause significant changes in the mechanical properties. The increased tensile strength value indicates that, under radiation, the cross-linking process took place. The irradiation process affects some changes in the fiber polymers structure as well as the non-cellulosic impurities that contained in the plant fibers [35]. However, further irradiation of the samples at 50 kGy led to a slight drop of the tensile strength by 3.6% from 33.3 MPa. Further irradiation at 150 kGy determined a greater drop of the tensile strength to 29.1 MPa from the value of 32.1 MPa recorded at 50 kGy, indicating a decrease of 9.3%. This suggests that the irradiated samples at 150 kGy underwent a bond scission process. The difference in tensile strength between the non-irradiated and irradiated samples at 150 kGy is of about 5%. This clearly reveals that gamma radiation of the hybrids led to slight changes in tensile strength [40,41]

The layering pattern K/OP/K exhibits higher tensile strength than OP/K/OP. On top of that, the pattern configuration OP/K/OP did not show considerable changes irradiated samples. Thus, an increase of 2.1% on the tensile strength for 25 kGy irradiated samples was noticed. Increased irradiation at 50 kGy improved the tensile strength by up to 10.5%, as the tensile strength values increased from 19.1 MPa to

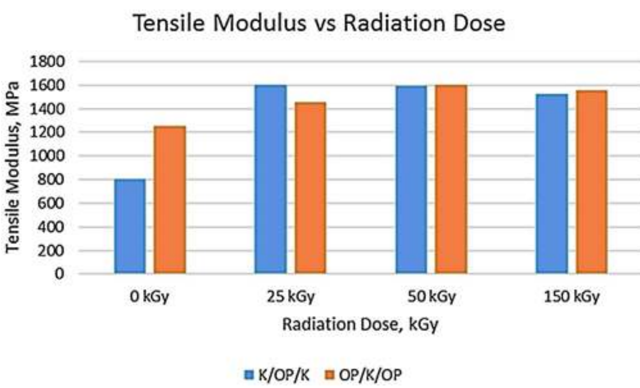

Fig. 4 – Tensile modulus of hybrid composites.

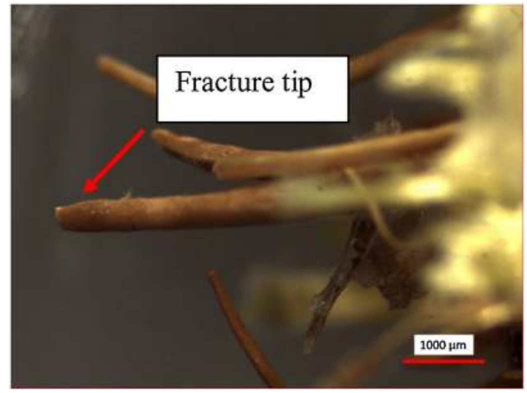

Fig. 5 – Oil palm EFB fibre fracture tip.

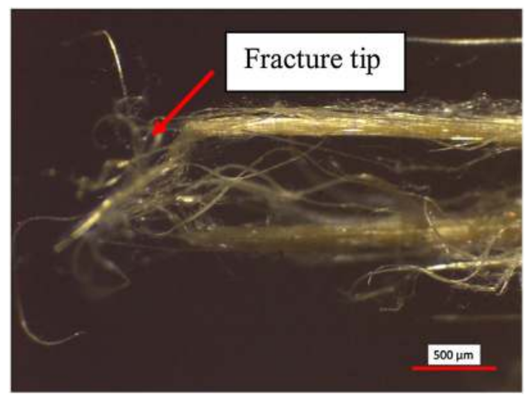

Fig. 6 – Kevlar fibre fracture tip.

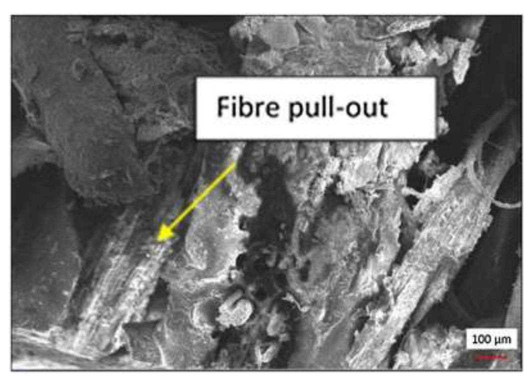

Fig. 7 – Without radiation.

21.1 MPa. Both OP/K/OP and K/OP/K pattern exhibited the same behaviour at 150 kGy, revealing a reduction in the tensile strength. The tensile strength at 150 kGy is 18.5 MPa. The difference between the tensile strength values was determined upon zero radiation and at 150 kGy is of merely 1%, otherwise said, the values are very close.

Fig. 4 displays the tensile modulus of the hybrid composites as a function of the gamma irradiation dose to which they were exposed. It can be easily remarked that the tensile modulus of K/OP/K in Fig. 4 depicts the same trend as that of tensile strength for the same series shown in Fig. 3. Without radiation, the modulus of tensile for K/OP/K samples was 0.81 GPa, and it increased to 1.6 GPa at 25 kGy radiation dose. A slight reduction, of 0.8%, in the tensile modulus was observed at 50 kGy. The tensile modulus decreased to 1.5 GPa, which is a drop of about 4.3% at 150 kGy. The OP/K/OP pattern showed a similar behaviour as that with regard to the tensile strength depicted in Fig. 3. A rise in the tensile modulus was recorded up to 50 kGy, followed by a decrease of 3% at 150 kGy.

From the above results, the hybrid composites underwent either cross linking or chain scission reactions depending on the dominant process at the absorbed dose. The cross-linking phenomena causes the formation of chemical bonds between two adjacent molecules [42]. This phenomenon increases the molecular weight of the material until it finally bounds into an insoluble three-dimensional network. Hence, with the cross linking process, it escalates the Young's modulus of the materials. On the contrary, the chain scission fractures the molecules, thus reduces the molecular weight and increase solubility [42]. Due to the fracture of molecules, process of chain scission results in the decrease of Young's modulus. Through gamma radiation process upon the lignin-containing fibes in EFB, this may result in the loosening and releasing the compactly entangles structure of the EFB fibres [43].

The fracture tip of oil palm EFB fibre and Kevlar is shown in Figs. 5 and 6, respectively. Fig. 5 clearly reveals brittle fracture of the oil palm EFB fibre, while Fig. 6 illustrates ductile fracture for Kevlar. Both images from Figs. 5 and 6 were obtained using microscope. Judging by the different fracture types of the oil palm EFB and Kevlar because oil palm EFB fibre is easier to break than Kevlar fibre. This difference governed the high tensile strength of K/OP/K, compared to that of the OP/K/OP hybrid composites.

3.2. *Morphological analysis*

The tensile fracture surfaces were observed by optical microscopy and FESEM, and are presented in Figs. 7–9. Fig. 7 reveals poor adhesion in the laminate, which results in fibre pull-out, leaving voids and thus indicating poor tensile strength. Fig. 8 illustrates the random orientation of the fibres with poor interfacial bonding that resulted in fibre bending when the load was applied, leading to a drop in the tensile strength. Moreover, Fig. 9 illustrates large voids on the rupture

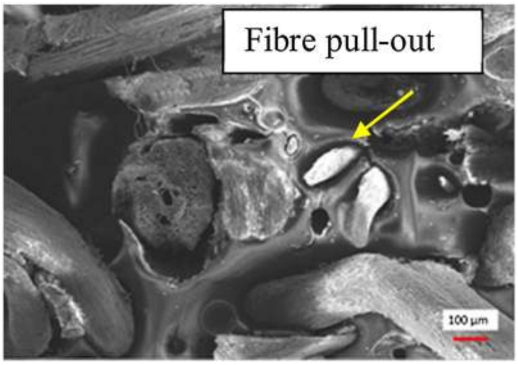

Fig. 8 – With radiation at 50 kGy.

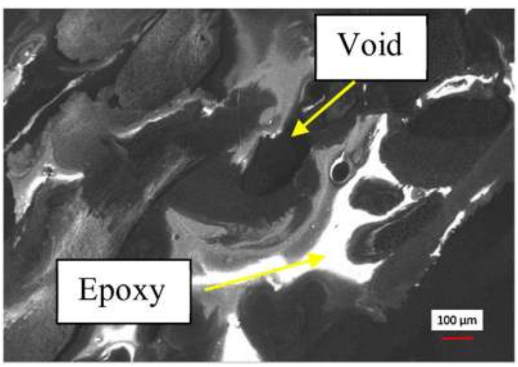

Fig. 9 – With radiation at 150 kGy.

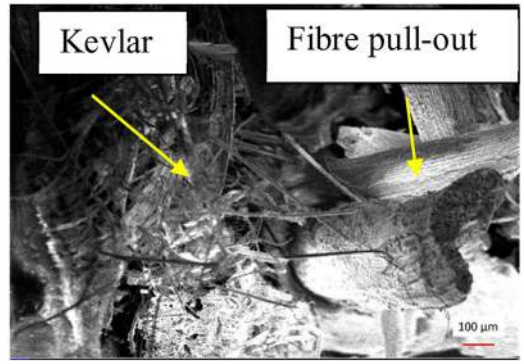

Fig. 10 – Without radiation.

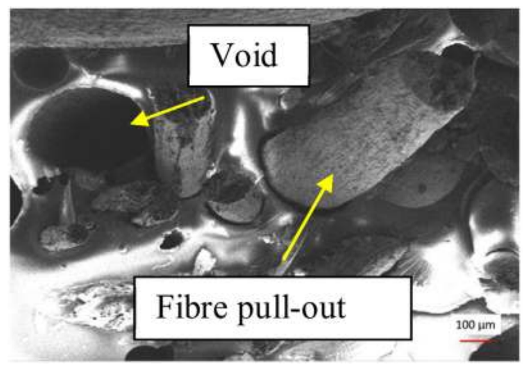

Fig. 11 – With radiation at 50 kGy.

surface, which are also responsible for poor tensile strength. Fig. 7–9 were obtained using FESEM.

The Kevlar fabric on woven form comprises of fibres in warp and weft direction and interlaced with each other. While, oil palm EFB possess randomly oriented dense architecture. During fabrication each plies was stacked together to form a laminated composites which improved the mechanical interlocking with adjacent lamina. When the woven hybrid composite is subjected to tensile load, the fibres in the transverse direction tend to straighten in addition to the longitudinal tension. This resulted in stress concentration on the fibre/matrix interface in the matrix which forms micro cracks and it propagates in transverse direction which lead to fracture of the fibre. This continues until the composites completely fractured.

Fig. 10 shows the fibre pull-out for both the oil palm EFB and Kevlar fibre. Since in OP/K/OP without radiation, the tensile strength of the material was much lower than that of L101, because of the characteristics of the oil palm fibre, which determined its brittle fracture, as depicted in Fig. 5. Fig. 11 shows the ruptured surface of the hybrid with the Kevlar fabric sandwiched between oil palm EFB fibre mats. Fig. 12 is an image of sample L204, revealing fibre pull-out and the corresponding holes in the sample – all this leads to lower tensile strength of the sample. Remarkably, larger voids appear on the fracture surface caused by the irradiation at 150 kGy as shown in Fig. 12. Figs. 10–12 were obtained using FESEM.

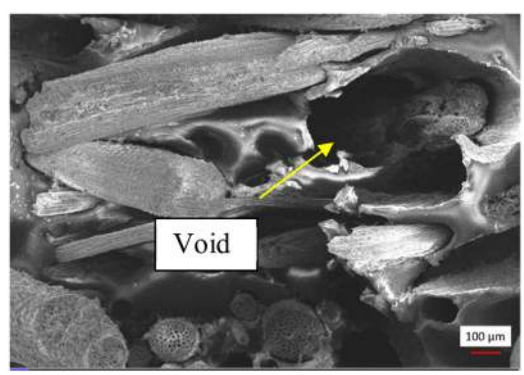

Fig. 12 – With radiation at 150 kGy.

The statistically significant difference of the tensile strength and modulus with respect to different composite samples have been investigated at different radiation doses using one way ANOVA analysis. The ANOVA test results of tensile strength and modulus are shown in Tables 3 and 4. The variance of the tensile strength and modulus were decomposed into two categories; between the groups (BG) and within the groups (WG). Ratio between the mean square (BG) to the mean square (WG) is the F-value. It was observed that there is a statistically significant difference in tensile strength and modulus among the composites samples with 95% confidence level

Table 3 – Tensile strength ANOVA test results.

Source	DF	S	M	F-Value	P-Value
Between Group (BG)	7	1356.2	193.739	27.85	0.000
Within Group(WG)	32	222.6	6.957		

DF-Degrees of freedom; S-Sum of Square; M-Mean Square.

Table 4 – Tensile modulus ANOVA test results.

Source	DF	S	M	F-Value	P-Value
Between Group (BG)	7	1958934	279848	5.76	0.000
Within Group(WG)	32	1554363	48574		

DF-Degrees of freedom; S-Sum of Square; M-Mean Square.

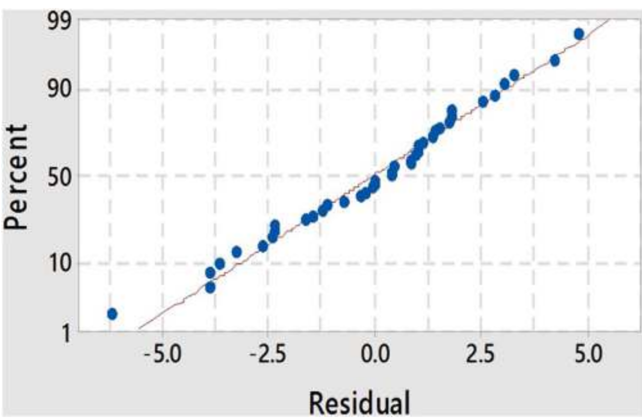

Fig. 13 – Normal plot of tensile strength.

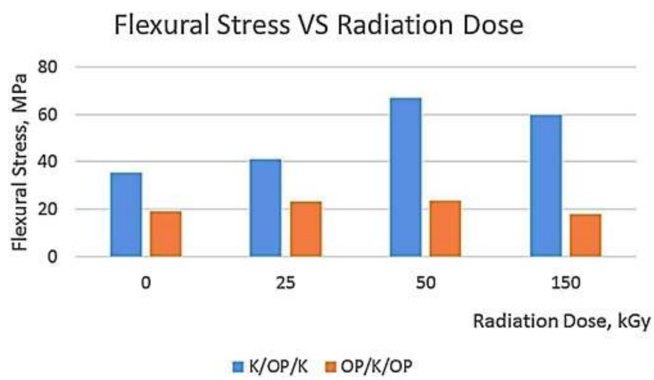

Fig. 15 – Flexural stress at various radiation dose for hybrid composites.

where P-value is less than 0.05 that rejects null hypothesis. Figs. 13 and 14 show the tensile strength and modulus normal probability plot. The data points in the normal probability plot are closer to the normalization line, hence, it corroborates the fitness of the model.

3.3. *Flexural properties*

The flexural properties of the hybrid composites are presented as a function of the radiation dose in Fig. 15. The hybrids with the configuration K/OP/K exhibited higher flexural properties as compared to OP/K/OP composites.

The variation of the flexural strength for different gamma radiation dose is shown in Fig. 15. It is observed that, the lay-

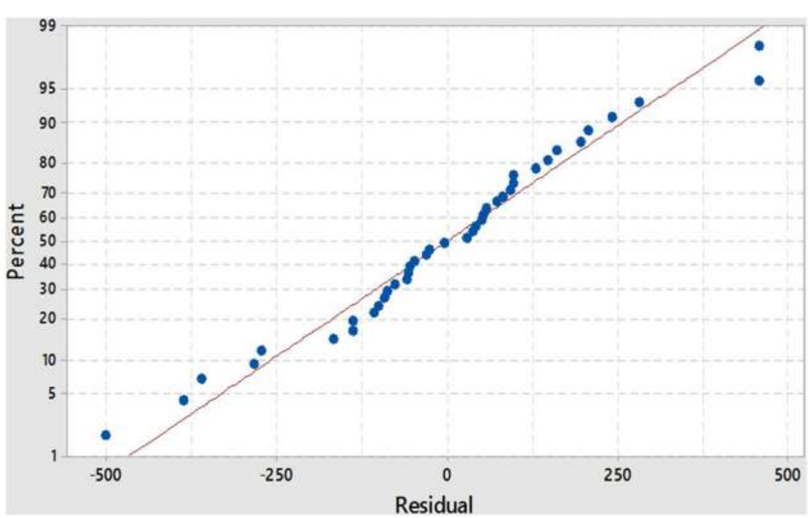

Fig. 14 – Normal plot of tensile modulus.

ering pattern K/OP/K, with the increase of radiation dose up to 50 kGy, the flexural strength shows a remarkable improvement due to the occurring cross-linking, which then enhances the interfacial adhesion. The flexural strength of the hybrids was 35.4 MPa, prior to irradiation, and increased to 41.2 MPa after the sample was irradiated at 25 kGy. Moreover, the flexural strength increased to 66.9 MPa for the sample irradiated at 50 kGy. However, when the radiation level was raised to 150 kGy, the flexural strength decreased to 59.6 MPa. Thus, increase in the radiation dose leads to a decrease of the flexural strength due to the chain scission process. Therefore, 50 kGy dose is considered the optimal dose for achieving enhanced flexural properties for this type of hybrid composites. The OP/K/OP pattern shows a similar results to that of the K/OP/K pattern. The flexural strength of the non-irradiated sample was 19.2 MPa, and increased to 23.4 MPa upon irradiation at 25 kGy, while at 50 kGy, a slight increase of the flexural strength to 23.6 MPa was recorded. At 150 kGy, the flexural strength decreased to 18.1 kGy. This clearly shows that irradiation at 150 kGy causes a considerable decrement in the flexural strength for both OP/K/OP and K/OP/K layering configurations.

From Fig. 15, it indicates that layering pattern with K/OP/K has higher flexural strength as compared to OP/K/OP pattern. Flexural property is a combination of different stresses which are the tensile and compression. During flexural test, the top layer of the hybrid composites experiences the compression phenomena while the bottom layer experiences the tension phenomena. Hence, the position of the types of fibre plays an important role in improving the flexural properties of the laminated composites [37]. Since the outer layer of the reinforcement controlled the flexural strength [37], this justify that the layering pattern for K/OP/K has better flexural strength compares to OP/K/OP layering pattern.

The flexural modulus as a function of the radiation doses given is shown in Fig.16. The flexural modulus for K/OP/K exhibits the same pattern as the flexural stress. The flexural modulus without any radiation is the lowest modulus value as compared to modulus of hybrid composites with radiation which is 3.9 GPa. The modulus strength increased to 4.4 GPa for hybrid composites radiated at 25 kGy. Further increased radiation until 50 kGy, the modulus strength still shows an increase in the strength where the modulus strength at 50 kGy for layering pattern of K/OP/K is 5.7 GPa. This is due to the crosslinking that occurred during the radiation process. However, at 150 kGy the modulus strength dropped to 5.4 GPa which indicates chain scission took place. Besides, oil palm EFB is an agricultural lignocellulosic waste materials that consists cellulose and lignin. Thus, chain scission indicates degradation of the materials. The degradation effect of radiation on the properties suggest that there exist reduction in the cellulose and lignin content of the EFB fiber [34]. Layering pattern for OP/K/OP shows that there is an improvement in the modulus strength when the hybrid composites were irradiated. In general, the flexural modulus for OP/K/OP layering pattern shows lower flexural modulus for layering pattern K/OP/K. For hybrid composites without radiation, 0 kGy the modulus strength is 2.1 GPa. When radiation of 25 kGy was applied to the hybrid composites, the modulus strength increase to 2.9 GPa. This indicates crosslinking has occurred to the hybrid. However, at 50 kGy, the modulus strength decreased to 3% from modulus strength at 25 kGy. At 150 kGy, the modulus strength shows an increment from the strength at 50 kGy radiation dose.

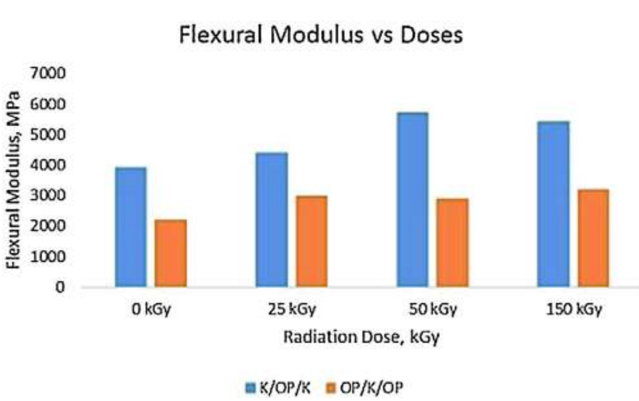

Fig. 16 – Flexural modulus versus radiation dose for hybrid composites.

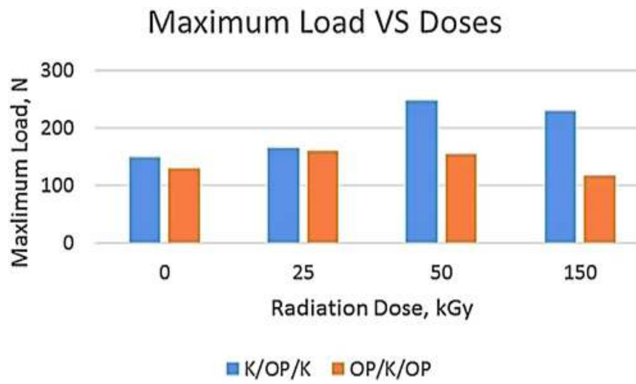

Fig. 17 – Maximum load with different radiation dose for hybrid composites.

Fig. 17 shows the maximum load that the hybrids can bear as a function of the radiation doses applied. The maximum for load-bearing capacity increased for irradiated samples. The maximum load was 149.97 N for K/OP/K before irradiation, however with further irradiation increased the maximum load to 165.38 N. Notably, the highest maximum load-bearing capacity was recorded at 247.06 N occurred at 50 kGy. The maximum load dropped when the radiation dose was raised to 150 kGy. The samples with the layering pattern OP/K/OP shows a similar behaviour. Without radiation at 0 kGy, the maximum load was 128.9 N, which then increased to 158.94 N at 25 kGy. The maximum load reduced to 116.58 N upon irradiation at 150 kGy, Thus, this indicates that at the radiation dose of 150 kGy, it determines a decrease in the maximum load-bearing capacity for both layering patterns.

The radiation effect on the flexural properties shows similar trend as in the tensile properties. When the hybrid composites were irradiated to gamma ray the flexural properties either showed improvement or vice versa. Gamma radiation is a form of electromagnetic radiation that carries energy depending on the type of radionuclide. The energy from the gamma radiation is transferred to the materials

Table 5 – Flexural strength ANOVA test results.

Source	DF	S	M	F-Value	P-Value
Between Group (BG)	7	7479	1068.47	16.01	0.000
Within Group (WG)	16	1068	66.75		

DF-Degrees of freedom; S-Sum of Square; M-Mean Square.

Table 6 – Flexural modulus ANOVA test results.

Source	DF	S	M	F-Value	P-Value
Between Group (BG)	7	24738224	3534032	25.45	0.000
Within Group (WG)	16	2221543	138846		

DF-Degrees of freedom; S-Sum of Square; M-Mean Square.

through collision between the radiation and the materials being exposed. This phenomena causing ionization process due to loss of bound electrons in the irradiated materials. This process initiates the cross linking and chain scission of the materials due to changes in the molecular structure. The molecular structures of the composites undergo modification mainly resulted from cross linking and chain scission effects depending on the absorbed radiation dose of the hybrid composites. Both processes coexist however which process is used will be determined depending on the chemical structure of the polymer, temperature, environment and dose rate [44]. In general, cross linking happens at lower dose while chain scission happens at higher dose.

The analysis on one way ANOVA has been conducted in order to investigate the statistically significant difference of flexural strength and modulus with respect to different composite samples at different radiation doses. The ANOVA test results of flexural strength and modulus are tabulated in Tables 5 and 6. It is found that the P-value of the F-test is less than 0.05, which rejects the null hypothesis. Thus, the statistically significant difference flexural strength and modulus is at 95% confidence level. The normal probability plot for flexural strength and modulus are exhibited Figs. 18 and 19. The points in the normal probability plot are closer to the normalization line. It further corroborates the fitness of the model.

Table 7 – Degree of crosslinking in oil palm EFB / Kevlar hybrid composites.

Radiation Dose, kGy	Average degree of crosslinking %
0	92.87
25	93.32
50	94.04
150	92.09

3.4. *Gel content*

The gel content experiment has been conducted to measure percentage of cross linking in the irradiated hybrid composites. Table 7 shows the variation of the degree of crosslinking of the oil palm EFB/Kevlar hybrid composites.

From the results, at 25 kGy there is an increase of percentage of the crosslinking phenomena. Further irradiation to 50 kGy, the percentage continue to increase. This indicates that there is a crosslinking phenomenon that occur to the hybrid composites when they are irradiated with gamma radiation. However, at 150 kGy, there is a drop in the percentage of the crosslinking. This suggest bond scission phenomena is likely to occur and resulted in the degradation of the materials which can be observed from the mechanical properties. From the results of the percentage, it is shown that there

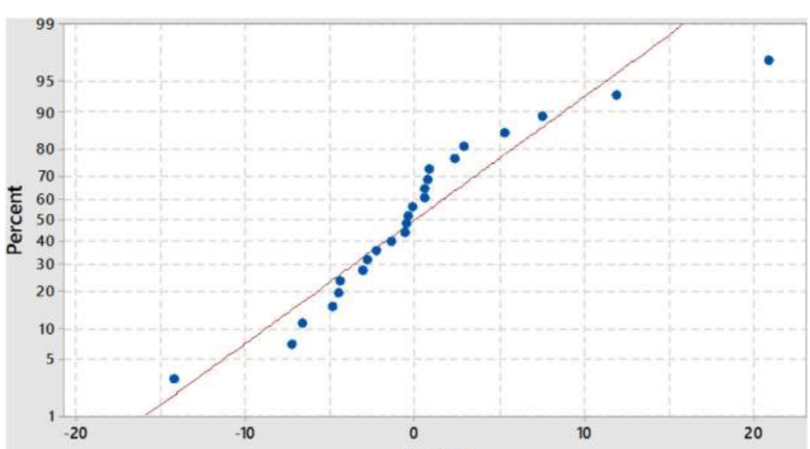

Fig. 18 – Normal probability plot for flexural strength.

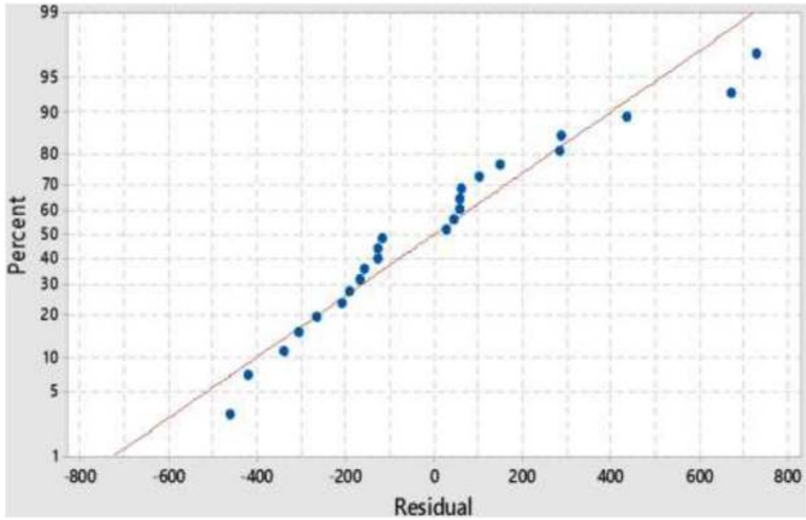

Fig. 19 – Normal probability plot for flexural modulus.

is a crosslinking phenomenon that occur, thus this explains the improvement of the mechanical strength when they were irradiated with gamma radiation since radiation crosslinking improves strength.

4. Conclusion

In this work, an attempt was made to fabricate oil palm EFB/Kevlar reinforced epoxy composites, with different layering pattern using hand lay-up method. The samples were then subjected to gamma radiation to investigate its effects on the tensile and flexural properties of the hybrids. It has been observed that gamma radiated hybrid composites showed the improved tensile and flexural properties compared to non-irradiated hybrid composites. This finding indicates that irradiated oil palm EFB and Kevlar hybrid composites could be exploited for several applications. Furthermore, the K/OP/K layering sequence hybrid composites exhibited higher mechanical properties, compared to those with the OP/K/OP layering configuration. The tensile properties for K/OP/K samples revealed quite remarkable improvements after the K/OP/K samples were irradiated at 25 kGy. An increase of the radiation level to 50 kGy has caused the tensile properties to drop to 3.6%. However, flexural properties exhibited an improvement at a radiation dose of 50 kGy. Comparing the layering pattern, K/OP/K shows better improvement in the flexural properties than OP/K/OP layering pattern. Not much flexural improvement properties observed at OP/K/OP layering pattern even when it is irradiation with gamma radiation. From the results, it can be concluded the layering pattern K/OP/K exhibits improved flexural properties when the combined effect such as the hybrid between oil palm EFB/Kevlar and gamma radiation applied to the composites. Overall, at 150 kGy, both the tensile and flexural strength recorded a noticeable decrement, indicating that the material's mechanical strength for this hybrid is decreasing when it is irradiated at 150 kGy.

As a further research direction, it can be explored if the findings of this study can be applied to develop other hybrid composites, based on the hybridization of Kevlar with jute, kenaf, sisal or hemp fibres, instead of oil palm EFB, in order to create novel high-performance materials for aerospace, automotive and shielding applications, as well as non-structural applications in radiotherapy and radio-diagnostic rooms.

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