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Characterization of Chemical-Treated and Gamma Irradiated Pineapple Leaf Fabric/Epoxy Composites: Surface Structure and Physico-Mechanical Properties

Gama Işını ve Kimyasal İşlem Uygulanmış Ananas Liflerinden Üretilen Kumaş/ Epoksi Kompozitlerin Karakterizayonu: Yüzey Yapısı ve Fiziko- Mekanik Özellikleri

Md. MONIRUZZAMAN[1] ,Mohammad ABDUL JALIL[1*], Md. NAZMUL HOSSAIN[1], Ismail HOSSAIN[1], Md. MANIRUZZAMAN[2]

[1]Department of Textile Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh
[2]Department of Chemistry, Khulna University of Engineering & Technology, Khulna, Bangladesh

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Sorumlu Yazara ait Orcid Numarası (Corresponding Author's Orcid Number) :

http://orcid.org/0000-0002-0006-8086

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CHARACTERIZATION OF CHEMICAL-TREATED AND GAMMA IRRADIATED PINEAPPLE LEAF FABRIC/EPOXY COMPOSITES: SURFACE STRUCTURE AND PHYSICO-MECHANICAL PROPERTIES

Md. MONIRUZZAMAN[1]
http://orcid.org/0000-0002-2064-1708
Mohammad ABDUL JALIL[1*]
http://orcid.org/0000-0002-0006-8086
Md. NAZMUL HOSSAIN[1]
Ismail HOSSAIN[1]
Md. MANIRUZZAMAN[2]

[1]Department of Textile Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh
[2]Department of Chemistry, Khulna University of Engineering & Technology, Khulna, Bangladesh

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ABSTRACT: The objective of this study is to investigate the effect of gamma irradiation and chemical (NaOH) treatment on the physico-mechanical properties of the pineapple/epoxy composites. The manual lay-up process was used here in fabricating pineapple leaf fabric (PALF fabric) reinforced composites. A scanning electron microscope (SEM) has been exploited for understanding the outward structure of composites. FTIR and EDS analysis recognized the existence of silicon and Si–O–Si/C–O–Si cross-linked configurations on the outward structure of composites. From the experimental results, it was found that gamma irradiation subjected composite sample had significant improvement in mechanical properties in comparison with composites reinforced with chemical treated pineapple leaf fabric and untreated composite. Tensile strength (TS), tensile modulus (TM), bending strength (BS), bending modulus (BM) and impact strength (IS) of gamma irradiated composite increased by approximately 71.26 %, 461.29%, 72.45%, 24.52% and 40.44% respectively compared to untreated composites. Furthermore, Gamma irradiated composite exhibited an increase of 49.98% TS, 40.46% TM, 35.82% BS, 11.21% BM and 12.44% IS compared to chemical treated pineapple leaf fabric composites. The reason for the improved physico-mechanical properties of gamma irradiated sample is due to the formation of crosslink in fiber and matrix molecules. The water absorption behavior of the composites was also tested.

Keywords: Chemical treatment, gamma irradiation, physico-mechanical properties, PALF/epoxy composite

GAMA IŞINI VE KİMYASAL İŞLEM UYGULANMIŞ ANANAS LİFLERİNDEN ÜRETİLEN KUMAŞ/ EPOKSİ KOMPOZİTLERİN KARAKTERİZAYONU: YÜZEY YAPISI VE FİZİKO-MEKANİK ÖZELLİKLERİ

ÖZET: Çalışmanın amacı, gama ışınları ve kimyasal (NaOH) işlemin ananas/ epoksi kompozitlerinin fiziko- mekanik özellikleri üzerine etkilerinin araştırılmasıdır. Ananas yapraklarından elde edilen lifler ile oluşturulan kumaşların takviye elemanı olarak kullanıldığı kompozitler, el ile yatırma tekniği kullanılarak üretilmiştir. Kompozitin dış yapısının anlaşılabilmesi için taramalı elektron mikroskobundan (SEM) faydalanılmıştır. Kompozitin dış yapısındaki silikonun mevcudiyeti ve Si–O–Si/C–O–Si çapraz bağlarının konfigürasyonu FTIR ve EDS analizleri ile tanımlanmıştır. Deneysel sonuçlar sayesinde, gama ışınları uygulanan kompozit numunelerinin mekanik özelliklerinin kimyasal işlem uygulanan ve uygulanmayan kumaşlar ile takviye edilmiş kompozit numunelerine göre önemli derecede iyileşme sağladığı belirlenmiştir. Gama ışınları uygulanan kompozitlerin kimyasal işlem uygulanmamış kompozitlere göre çekme dayanımı (ÇD), çekme modülü (ÇM), eğilme dayanımı (ED), eğilme modülü (EM) ve darbe dayanım (DD) değerleri yaklaşık olarak sırası ile %71,26, %461,29, %72,45, %24,52 ve %40,44 oranlarında artmıştır. Bu duruma ek olarak, gama ışınları uygulanan kompozitler kimyasal işlem uygulanmış kumaşların takviye elemanı olarak kullanıldığı kompozitlere göre %49,98 ÇD, %40,46 ÇM, %35,82 ED, %11,21 EM ve %12,44 DD oranlarında artış sağlamıştır. Gama ışınları uygulanın numunenin fiziko- mekanik özelliklerinin iyileşmesinin sebebi matris ve lif molekülleri arasında çapraz bağların oluşmasıdır. Ayrıca kompozitlerin su absorbsiyon davranışları test edilmiştir.

Anahtar Kelimeler: Kimyasal işlem, gama ışınları, fiziko- mekanik özellikler, Ananas liflerinden üretilen kumaş/ epoksi kompozitleri

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Sorumlu Yazar/Corresponding Author: *drjalil@te.kuet.ac.bd*
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1. INTRODUCTION

With increasing the environmental consciousness, the usage of natural fiber-reinforced polymer composite has attracted more attention from scientists and engineers due to its biodegradability, satisfactory mechanical properties, non-toxicity and lower cost now-a-days [1,2]. Composite materials are being applied long since in various engineering applications for example, automobile, furniture, packaging, military purposes, building constructions, and naval industries etc [3,4]. In recent years, numerous studies were accompanied on natural fibers to use as reinforced material in composite to replace synthetic fibers like glass, carbon fiber because natural fiber composites are more economical, biodegradable and easily decomposable in the environment compared to synthetic fiber based-composites. These also reduce the wear on manufacturing equipment and minimize the health hazard. [5-8].

Among the different natural fibers, pineapple leaf fiber comprises high alpha-cellulose content which exhibits higher mechanical properties (70-82%) and low microfibrillar angle [9]. PALF is originated from the leaves of the plant *Ananas comosus* is one of the world's top tropical fruits, other than citrus and banana[10,11]. Pineapple leaves are discarded as agricultural waste which can be obtained easily without any extra cost and can be used for manufacturing natural fibers. So-called bio-waste can be utilized in value-added fiber production and diversified composites. Moreover, compared with the non-renewable sources of synthetic fibers, natural fibers such as pineapple leaf fibers are easily available and are harvested yearly, making these sources renewable and inexhaustible [12]. In maximum of the polymer matrix pineapple leaf fiber contributes as a reinforced fiber as it is economical, showing better performances when compared with other natural fibers. Pineapple leaf fibers are constituted with ash (1.1%), lignin (5–12%), and holocellulose (70–82%) with good mechanical properties [11,13,14]. Besides, pineapple leaf fibers have been used to reinforce polymers in bio-composite production and have been shown to significantly enrich the physico-mechanical properties of bio-composites [15,16].

PALF absorbs moisture from air thus make it hydrophilic in nature and moisture content varies between 3% to 13% because the chemical structure of PALF hydroxyl groups are present. With the help of several chemical treatments and gamma radiation, the hydrophilicity of PALF fibers can be changed and reduced which increase the fiber/matrix adhesion of the composite materials resulting in better composite quality and properties. Unsaturated polyester and epoxy are used as thermoset polymer and found to be the potential matrix materials for PALF fibers [13,20].

Now-a-days, epoxy resins are used as a thermoset polymer for various engineering applications. It is widely used in electrical industries, aerospace, automotive and marine industries. Epoxy resin is well-known for its better mechanical and thermal properties. Epoxy can also absorb less moisture and can be processed easily. The other advantages include excellent chemical resistance [21-23].

The main problems of PALF are hydrophilic; there is no good bo nding to the hydrophobic matrix, especially at high temperatures [24]. At present, many scientists are trying to overcome this problem by using different kinds of ways. The interfacial consistency between fiber and polymer could be enhanced by using gamma irradiation and chemical treatments such as dewaxing, NaOH treatment, cyanoethylation and grafting of acrylonitrile monomer onto dewaxed natural fiber [13].In addition, surface modification by a chemical such as sodium hydroxide (NaOH) can reduce water absorption and enhance mechanical properties [25]. For that reason, we consider NaOH for the chemical treatment of PALF fabric. It is also an easy and cost-effective process.

Moreover, in this research work, gamma irradiation has been exposed to composites to increase interfacial bonding strength between the fiber and polymer matrix.

In this study, it is tried to show the effects of gamma irradiation and chemical treatment to improve the physico-mechanical properties. And also, a comparison has been made to evaluate the physico-mechanical properties and water absorption behavior among gamma irradiated composite and composite reinforced with chemical (NaOH) treated pineapple leaf fabric and untreated composite.

2. EXPERIMENTAL SECTION

2.1 Materials

The PALF plain woven fabric with EPI 13, PPI 13, GSM 200 and yarn count 345 tex was procured from the local market of Bangladesh. The commercial-grade Epoxy LY556 (density 1.08–1.20 g/cm^3) and the hardener Araldite HY951 were collected from the local market. All of these chemicals were used without any further modifications. The properties of PALF used in this study are listed in Table 1 [17,18].

Table 1. Properties of PALF used to make composites.

Properties	PALF
Density (g/cm^3)	1.44
Youngs Modulus (GPa)	6.26
Tensile strength (MPa)	170
Specific modulus (GPa/g/ cm^3)	-
Elongation at break (%)	1.6
Moisture absorption (%) at 24 hrs	11-12

2.2 Chemical Treatment of PALF Fabric

Firstly 5% w/v NaOH solution was prepared. Then the pineapple leaf fabric was dipped in the NaOH solution and treated at room temperature for 2 hours. After chemical (alkali) treatment, the samples were washed well thoroughly with distilled water along with a few drops of acetic acid to neutralize pH. Finally, the treated PALF fabric was dried in an oven for 20 hours at 80^o C for complete removal of moisture.

2.3 Fabrication of Composites

In this study, a mould with dimensions of (190 mm × 140 mm × 3 mm) was used for the fabrication of composites. The PALF fiber-based epoxy composites were fabricated using a manual lay-up process. Epoxy hardener and resin were mixed in a beaker properly. For laminating PALF- reinforced fabrics the mixture become compatible. First of all, a thin plastic sheet was placed on the dried bottom mould plate. And a few amounts of epoxy resin mixture were sprayed uniformly on the plastic sheet. Then, PALF fabric was cut as per the mould plate size and placed on the epoxy resin impregnated plastic sheet. Then a part of the epoxy resin mixture was sprayed uniformly onto the surface of the fabric. The similar process was repeated for each layer on the mat and so on. Four layers of PALF fabric were reinforced to epoxy resin. After placing a thin plastic sheet on the top layer of reinforcement a roller was used to remove any air bubble formed during the process and the top mould was placed with load of about 40 kg on the plastic sheet. After that, curing was done at normal temperature for 24 hours. Finally, the mould was opened and manufactured composite laminate is taken out and further cut into strips for mechanical testing. Figure 1 shows the manufactured PALF/epoxy composite by manual lay-up process. And the percentages of materials used in composites are shown in Table 2.

Table 2. Percentages of materials used in composites

Weight fraction (%)		Volume fraction (%)
W_f	W_m	V_f
27.55	72.45	24.06

Weight fraction was calculated by the equation (1), [19].

$$W_f = \frac{W_f}{(W_f+W_m)} \text{ and } W_m = \frac{W_m}{(W_f+W_m)} \qquad (1)$$

Fiber volume fraction was also calculated by using following equation (2), [19].

$$V_f = \frac{\left(\frac{W_f}{\rho_f}\right)}{\left(\frac{W_f}{\rho_f}\right)+\left(\frac{W_m}{\rho_m}\right)} \qquad (2)$$

Here, W_f is the fiber weight fraction, W_m is the matrix weight fraction, V_f is the fiber volume fraction, ρ_f is the fiber density and ρ_m is the matrix density.

2.4 Gamma Irradiation

The composite specimens were irradiated using a Co-60 gamma source accelerator at a dose of 5kGy. All the specimens were irradiated at room temperature. Gamma irradiation was carried out at Bangladesh Atomic Energy Commission (BAEC), Savar, Dhaka, Bangladesh.

2.5 Mechanical Testing

The Hounsfield series (INSTRON 1011, UK) Universal Testing Machine (UTM) with a cross head speed of 10 mm/min was used to measure the tensile strength and tensile modulus of composites according to ASTM D 638-01 as shown in Figure 2 (a). Tensile Strength equals to Applied load / Cross-sectional area of the load bearing area. In this study, tensile strength and tensile modulus are expressed in MPa. The test specimen dimensions were (ISO 14125): 60 mm × 15 mm × 3 mm (length × width × thickness). Before testing, the samples were conditioned for two days at 25^o C and 50% relative humidity and all the tests were carried out under the same conditions. Five specimens were tested and the mean values were recorded for each test and type of composites.

Tensile strength and modulus were calculated by equations (3) and (4), respectively.

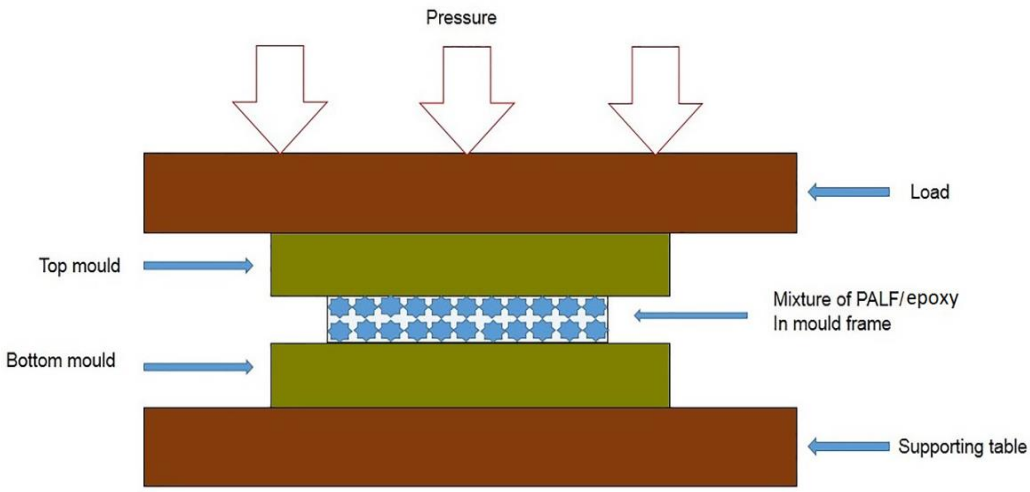

Figure 1. Schematic diagram of PALF/epoxy manufacturing process.

$$Tensile\ strength,\ \sigma = \frac{Force}{Area} = \frac{Fmax}{A} \quad (3)$$

Here, F_{max} and 'A' represent the maximum load to the sample (KN) and the cross-sectional area of the sample (m^2) respectively.

$$Tensile\ Modulus,\ Y = \frac{d\sigma}{d\varepsilon} \quad (4)$$

Here d is stress at yield point and dis strain at yield point.

The same universal testing machine was used to assess the bending strength and bending modulus and the alike testing condition according to ASTM D 7264. Bending properties can also be calculated using the same machine as described for the tensile properties.

Equations (5) and (6) were used to measure the bending strength and bending modulus respectively.

$$Bending\ Strength,\ \sigma = \frac{3FL}{2bd^2} \quad (5)$$

Here F represents the load (force) at the fracture point (KN), L represents the length of the support span (mm), b represents the width (mm), and d represents the thickness(mm).

$$Bending\ Modulus,\ E_{bend} = \frac{L^3F}{4wh^3d} \quad (6)$$

Here w &h indicate the width and height of the sample (mm) respectively and *L* is the distance between the two external supports (mm) and *d* is the deflection because of the load *F* applied at the mid of the sample (KN).

Izod impact test for various composite specimens was conducted according to ASTM D-256 as shown in Figure 2 (b). The length and the width of the specimens used for impact tests were 61.5 mm and 12.7 mm respectively. The impact strength is determined by the following equation (7).

$$I = \frac{K}{A} \quad (7)$$

Here I indicates the Impact strength (KJ/m^2), K represents the energy required to break the specimen (KJ) and A indicates the cross-section area (m^2).

2.6 Water Absorption Behavior

Water uptake of the composite was determined as stated by the ASTM D570. The PALF/epoxy composite samples (20 mm × 10 mm × 3 mm) were prepared from the bulk sample to use for testing. Before the test, the samples were dried in an oven at 60^0C until a constant weight was acquired. The primary weight (W_0) of the dried samples were measured and then immersed in a glass beaker having distilled water for 48 hrs at normal temperature. After that, the dipped samples were eliminated and rubbed the surface of the samples smoothly to remove the surplus water. The final weight (W_{48h}) of the samples were measured instantly. The percentage of water uptake was then calculated using the equation (8).

$$Water\ uptake\ (\%) = \frac{W_{48h} - W_0}{W_0} \times 100 \quad (8)$$

2.7 SEM Analysis

Morphological observations of the surface of the composites with untreated, chemical treated and gamma irradiated specimens were made at room temperature using SEM (Jeol-JSM 7600M, Japan). The morphological properties show the variation in the mechanical properties through phase information changes of composite specimens. Scanning Electron Microscopy (SEM) experiments were performed under an accelerating voltage of 1 kV.

(a) (b)

Figure 2. (a)Universal testing machine (b) Impact testing machine.

2.8 EDS Study

The elements on the surface of the composites before and after the chemical treatment and gamma irradiation were tested by EDS (Jeol-JSM 7600M, Japan). The contents of the elements C, O, Na and Si on the surface of the composites were tested. Experiments with energy-dispersive X-ray spectroscopy were carried out under a 10 kV accelerating voltage.

2.9 ATR-FTIR Analysis

FTIR spectroscopy is used to perceive the functional groups in composites. It assists to identify the changes in the chemical compound of composites before and after the chemical treatment and gamma irradiation. ATR-FTIR analysis was carried out using IR Tracer-100, Shimadzu (Japan). The spectra were acquired in the absorption band mode in the range from 4000 cm^{-1} to 600 cm^{-1}.

3. RESULTS AND DISCUSSION

The effects of gamma irradiation and chemical treatment on physico-mechanical properties like tensile strength, tensile modulus, bending strength, bending modulus and impact strength of PALF/epoxy composites have been studied experimentally and also results are discussed as well as compared with untreated PALF\epoxy composites. The results are discussed in graphical formation.

3.1 Evaluation of Tensile Strength

The effects of gamma irradiation and chemical treatment on tensile strength of PALF/epoxy composites are depicted in Figure 3. It is noticed from Figure 3 that the tensile strength of the PALF/epoxy composite increases significantly with the chemical treatment and gamma irradiation compared to untreated composite. Approximately, tensile strength increases about 14.19% of composite reinforced with chemical treated pineapple leaf fabric compared with the untreated composite. The improvement in the tensile strength of composite reinforced with chemical treated pineapple leaf fabric is due to the fact that the chemical treatment enhanced the binding properties of the fiber-matrix by removing natural and artificial impurities from the fabric surface. Similarly, tensile strength increases about 71.26% of 5kGy gamma irradiated composite compared to the untreated composite due to cross-linking. Gamma irradiation may remove moisture from the composites. This may contribute to improved adhesion of the fiber-matrix.

3.2 Evaluation of Tensile Modulus

The tensile modulus of PALF/epoxy composite is illustrated in Figure 4. It is seen that tensile modulus of the tested specimen shows a similar pattern like tensile strength. It is perceived from the figure that the tensile modulus of the PALF/epoxy composite also increases significantly with chemical treatment and gamma irradiation when compared with untreated composite. Almost, the tensile modulus of chemical treated PALF/epoxy composite increases by about 299.59%. This is due to the fact that the fibers lose hydroxyl groups due to chemical treatments, which reduce the hydrophilic nature of the fibers and increase the tensile properties. Equivalently, the tensile modulus of gamma irradiated PALF/epoxy composite increases about 461.29% compared with the untreated composite due to better cross-linking between fiber and matrix. The reason behind that composite moisture may be eliminated by gamma irradiation. Cross-linking is a mechanism in which molecules bind together to form larger molecules, resulting in enhanced tensile properties.

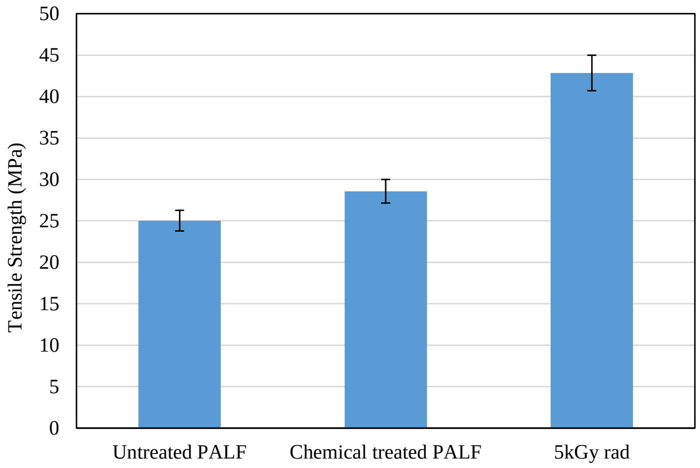

Figure 3. Effect of gamma irradiation and chemical treatment on tensile strength of PALF/epoxy composites.

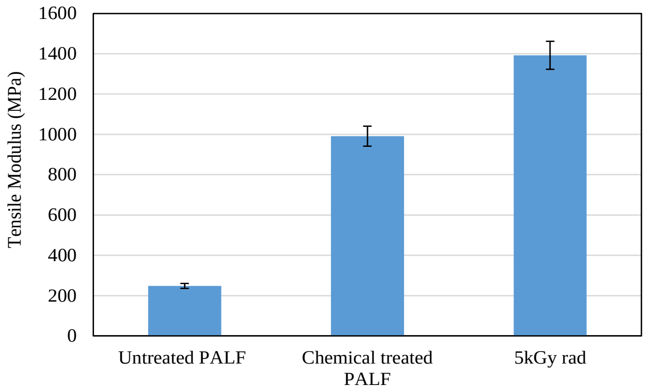

Figure 4. Effect of gamma irradiation and chemical treatment on tensile modulus of PALF/epoxy composites.

3.3 Evaluation of Bending Strength

It is noticed from Figure 5 that with the exposure of gamma irradiation and chemical treatment the bending strength of the PALF/epoxy composite shows an improvement compared with untreated composite. Approximately, bending strength increases by 72.45% and 35.82% of gamma irradiation exposed composite compared with the untreated and composite reinforced with chemical treated pineapple leaf fabric respectively. The bending strength of the composite increased due to the gamma irradiation, which induced greater adhesion between the polymer matrix and the fibers. Bending strength of chemically treated specimen increases by 26.97% than untreated PALF/epoxy composite.

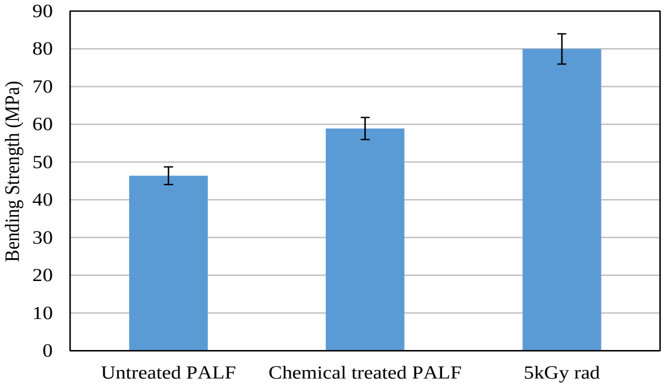

Figure 5. Effect of gamma irradiation and chemical treatment on bending strength of PALF/epoxy composites.

3.4 Evaluation of Bending Modulus

The improvement of the bending modulus of PALF/epoxy composite material is seen in Figure 6 which is exposed to gamma irradiation. The bending modulus of gamma radiation exposed specimen shows the highest value about 4.63 GPa and bending modulus of it is 11.21% and 24.51% higher than composite reinforced with chemical treated pineapple leaf fabric and untreated PALF/epoxy composite specimens due to cross-linking phenomenon and interfacial adhesion between matrix and fiber has been improved. The bending modulus of the chemical treated specimen is increased by about 11.97% than the untreated specimen.

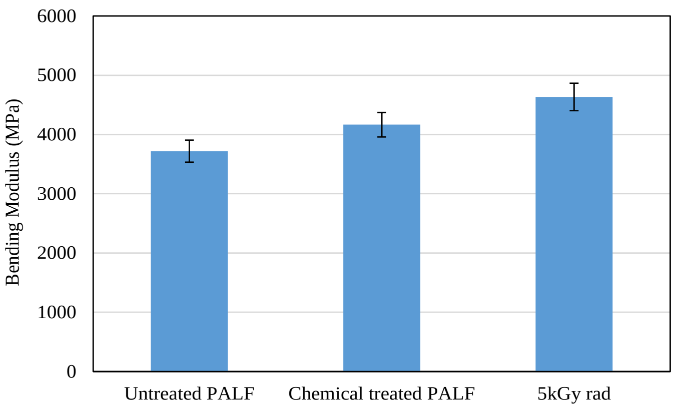

Figure 6. Effect of gamma irradiation and chemical treatment on bending modulus of PALF/epoxy composites.

3.5 Evaluation of Impact Strength

Figure 7 depicts the impact properties of PALF/epoxy composites. The result affirms that gamma irradiated composite shows the highest impact strength than untreated and chemical treated pineapple fabric composites due to crosslinking. Higher impact strength values of gamma irradiated composites compared with untreated and composites reinforced with chemical treated pineapple leaf fabric are probably an indication of better matrix-fiber interaction assisted by gamma irradiation. The highest value of Izod impact strength of gamma irradiated specimen is reported to be 147.5 KJ/m^2, an improvement of 40.44% and 12.44% approximately over that of untreated and chemical treated specimen respectively.

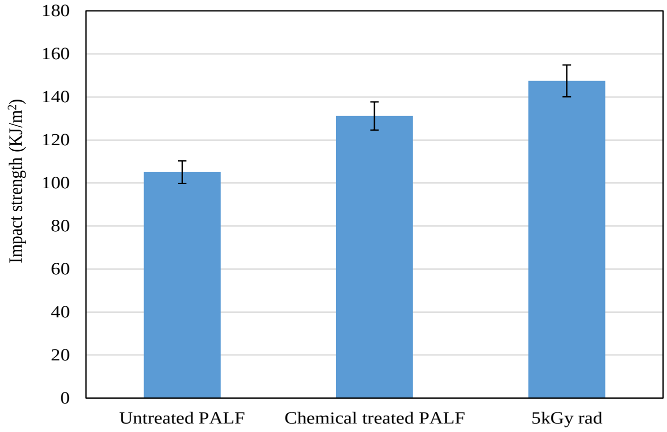

Figure 7. Impact strength of PALF/epoxy composites

3.6 Water Absorption Behavior

Water absorption of untreated, chemical treated and gamma irradiated composites are shown in Figure 8. It is exhibited from the figure that chemically treated samples attained the highest water absorption for 48 hours than the untreated and gamma irradiated samples due to all the non-cellulosic impurities and interfibrillar matrix material, like as pectin and lignin removed by chemical treatment. As a result, micro gaps may be increased. As a result, the small water molecules easily penetrate into fiber surface because they have more space, resulting in more water absorption by the composite reinforced with chemical-treated pineapple fabric [26].Gamma irradiation composites have also shown to decrease the water absorption potential over untreated and composites reinforced with chemical treated pineapple leaf fabric. Gamma irradiated composites had greater adhesion of matrix fiber, which could be responsible for a lower propensity of water uptake. Due to gamma radiation the hydroxyl groups were reduced, crystalline region of the gamma irradiated composite was increased by a crosslinking phenomenon, as a result of which water absorption activity of the composites decreased [27].

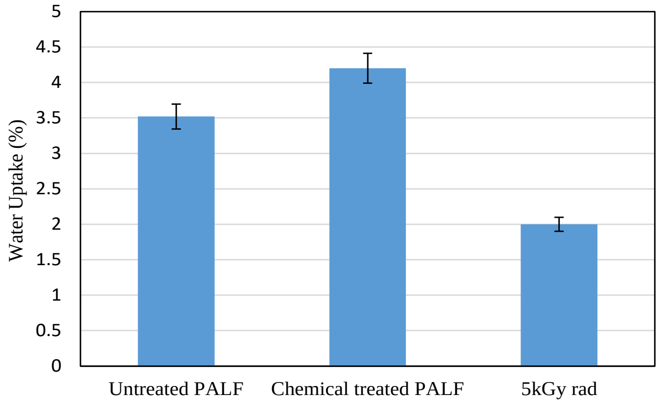

Figure 8. Water uptake (%) of PALF/epoxy composites

3.7 SEM and EDS Analysis

Figure 9 shows the morphology of the surface and energy spectrum of the composites. The SEM image of Figure 9(a–b) shows that there were no significant changes of the surface between the untreated and composites reinforced with chemical treated pineapple leaf fabric but Figure 9c, gamma irradiated sample shows that there was significant change of the composite surface. This indicates that gamma irradiation removes moisture from the composites and makes stronger bonding between the fiber and the polymer matrix. It can be seen from the EDS that the untreated composites contain a very high amount of Si and the surface of chemical treated and gamma irradiated composites contain different contents of Si. This indicates that chemical and gamma irradiation have effectively grafted to the surface of composites. Table 3 shows the mass percentages and atom percentages of C, O, Si and Na on the surface of untreated, chemical treated and gamma irradiated composites. The results show that oxygen and carbon have been the main peaks in untreated, chemical treated and gamma irradiated composites. This is because they are the main components of PALF cellulose, hemicellulose, and lignin in PALF [28,30]. A high amount of Si material was found on the surface of the untreated composites, with a mass percentage and atom percentage were 0.94% and 0.48% respectively. Nevertheless, the Si contents on the surface of chemical treated and gamma irradiated composites decreased due to chemical and gamma irradiation respectively. This means that hemicelluloses are removed from the PALF and so increase the crystallinity of the composites. As a result, fibers are strongly gripped by the matrix materials.

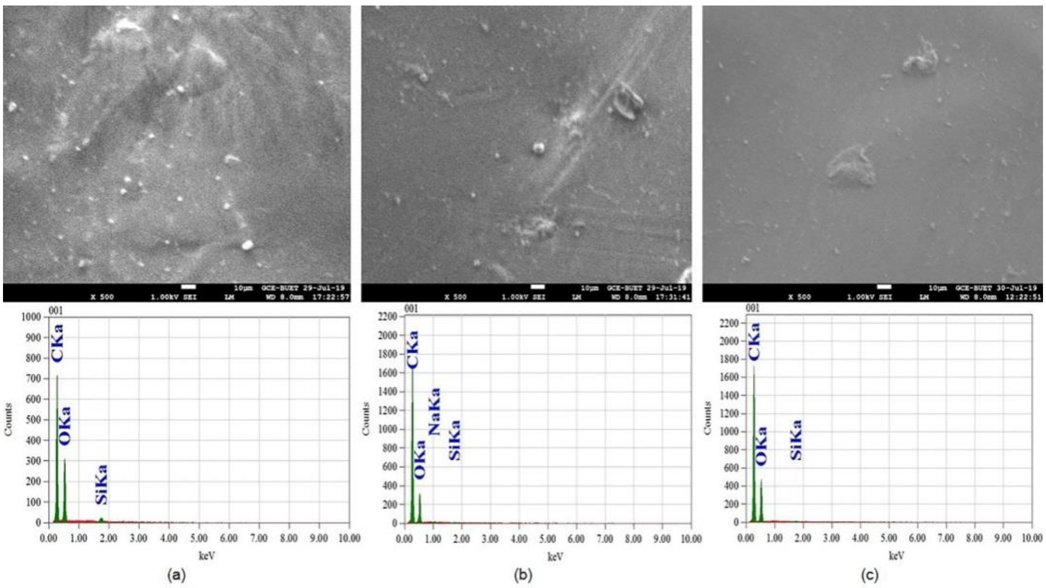

Figure 9. SEM image of (a) Untreated (b) Chemical treated and (c) Gamma irradiated with 5kGy PALF/epoxy composites.

Table 3. The elements and their contents for untreated, chemical treated and gamma irradiated composites.

Sample	C (%)		O (%)		Si (%)		Na (%)	
	Mass	Atom	Mass	Atom	Mass	Atom	Mass	Atom
Untreated	62.16	68.67	36.90	30.85	0.94	0.48	-	-
Chemical treated	74.20	79.45	25.41	20.39	0.19	0.09	0.20	0.07
Gamma Irradiation	69.23	75.02	30.63	24.92	0.14	0.06	-	-

3.8 FTIR Spectra Analysis

FTIR spectra of untreated, chemical-treated and gamma irradiated PALF/epoxy composites are shown in Figure 10 from wave number 4000 cm^{-1} to 600 cm^{-1}. The chemical composition and the peak positions of untreated, chemical-treated and gamma irradiated PALF/epoxy composites are shown in Table 4. Absorption bands at 3431.64 cm^{-1} and 2913.16 cm^{-1} for untreated composites were correlated with -OH and C–H cellulose stretching vibration, respectively [28,29,31]. But, the relative peaks occurred at 3441.67 cm^{-1} and 2923.16 cm^{-1}, which became weaker after chemical treatment and gamma irradiation. The reasoning for this is that the -OH groups of cellulose were changed by chemical and gamma irradiation to form hydrogen bonds, which reduced the vibration of both C–H bonds and -OH groups. Cellulose -OH groups were better adjusted by chemical and gamma because the content of cellulose is higher than that of hemicelluloses and lignin in PALF. The peaks at 1726.68 cm^{-1}, 1452.49 cm^{-1} and 1280.99 cm^{-1} were due to the C=O stretching of carboxylic acid in hemicellulose, -CH_2 stretching of cellulose and the C–O stretching of lignin, respectively [32-34]. The chemical and gamma irradiation decreased the vibration peaks amplitude at 1280.99 cm^{-1} because the portion of the lignin was protected by the epoxy hardener. The vibration peak at 1068.99 cm^{-1} was due to the C–OH stretching vibration in lignin [35,30], which was decreased after treatment . The Si–OH stretching peak was more pronounced at 1066.96 cm^{-1} (chemical and gamma irradiated). It should be noted that the latest vibration peaks of 1066.96 cm^{-1} and 1123.46 cm^{-1} were created by Si–OH stretching vibration and C–O–Si/Si–O–Si stretching vibration [36]. The vibration intensity of the PALF treated by gamma irradiation was the highest at both 1066.96 cm^{-1} and 1123.46 cm^{-1}. The FTIR analysis showed that the gamma irradiated composites had been successfully modified and that the condensation of dehydration between the Si–OH and the hydroxyl groups formed C–O–Si functional groups on the surface of the fiber.

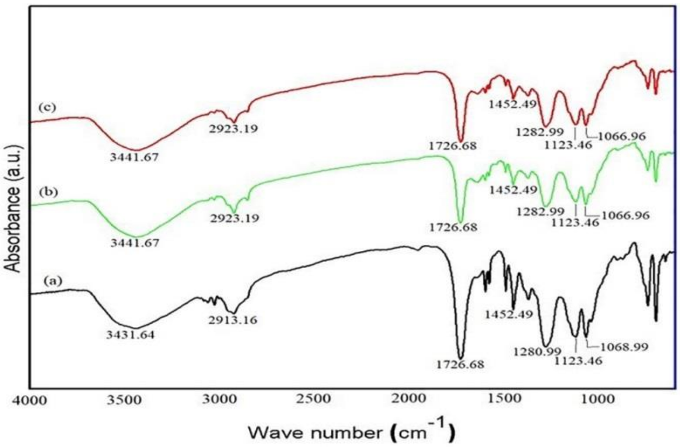

Figure 10. FTIR spectra of (a) Untreated (b) Chemical treated and (c) Gamma irradiated with 5kGy PALF/epoxy composites.

4. APPLICATIONS

The application of natural fiber as reinforcement in the polymer matrix has brought worldwide attention to environmental awareness. Natural fiber reinforced polymer composites in many applications have proved to be an alternative to synthetic fiber reinforced polymer composites [37,38]. Various types of natural fibers such as pineapple, jute, bamboo and hemp reinforced polymer composites have received considerable prominence in various applications in the automotive, packing and construction industries etc. [39,40]. In the United states, several large companies have used natural fibers such as jute, hemp, and flex to make different exterior and interior components for automobiles [41].The widespread application of natural fiber as reinforcement in polymer composites due to its relatively high strength, low specific weight, relatively low production cost, fully biodegradable, relatively good mechanical properties, usable and sustainable sources as compared to synthetic fibers [39,42]. On the other hand, natural fiber polymer composites such as water absorption have a physical disadvantage and this disadvantage has hindered their performance [43]. In this study, it is found that gamma irradiated pineapple leaf fabric/epoxy composites have better mechanical properties and low water absorption behavior than untreated composite and composite reinforced with chemical treated pineapple leaf fabric. For that reason, gamma irradiated PALF/epoxy composites can be used in fishing boats, false ceiling, roofing, railing systems and fencing, constructing drains and pipelines etc.

Table 4. Assignments and peak positions in FTIR spectra of untreated, chemical treated and gamma irradiated composites.

Bond/stretching	Untreated composite (cm^{-1})	Chemical treated composite (cm^{-1})	Gamma irradiated composite (cm^{-1})	References
-OH stretching of cellulose	3431.64	3441.67	3441.67	[28,29]
C-H stretching of cellulose	2913.16	2923.19	2923.19	[31]
C=O stretching of hemi-cellulose	1726.68	1726.68	1726.68	[32]
-CH_2 stretching of cellulose	1452.49	1452.49	1452.49	[33]
C-O stretching of lignin	1280.99	1282.99	1282.99	[34]
C-O-Si/or Si-O-Si stretching	1123.46	1123.46	1123.46	[35,30]
C-OH/ or Si-OH stretching	1068.99	1066.96	1066.96	[30,36]

5. CONCLUSION

Throughout tropical regions, pineapple leaf fiber is very popular and easy to extract fibers from the leaves. The use of pineapple leaf fiber in composite material is a new type of materials that can be economical, environmentally sustainable, and recyclable. Through this study it was observed that their interface bonding strength highly influenced the physico-mechanical properties of pineapple/epoxy composites. Gamma irradiated composite samples showed enhanced adhesion properties of the fiber matrix relative to untreated samples and composites reinforced with chemical pineapple leaf fabric. From the standpoint of the results of FTIR, it was stated that a strong interaction between fiber and epoxy resin take place in gamma irradiation composite. Besides, weak interactions occur between untreated and composite reinforced with chemical treated pineapple leaf fabric in this work. From the morphological analysis, it has been concluded that micrographs suggest an adhesive failure in the interface both untreated and composites reinforced with chemical treated pineapple leaf fabric. This means that fibers are insecurely gripped by the matrix material. On the contrary, epoxy-based gamma irradiation composite reinforced showed considerable matrix failure together with the PALF fibers. This result denotes that fibers are firmly gripped by the matrix material. From this point of observation, FTIR analysis offered a good agreement with the EDS and SEM results. Thus, the uses of the synthetic fiber-reinforced composite may be replaced by the gamma irradiated PALF reinforced composite. There lies a bunch of future scopes if we can replace synthetic based reinforced composites by PALF made composites. And it will also protect our environment from the contamination of synthetic materials by providing good mechanical properties. On the contrary, pineapple leaf fiber is an agro-waste which is rich in cellulose, comparatively inexpensive. So, we could achieve zero waste management by using this fiber, turning the pineapple "Trash" into "Money" and encouraging the agriculture-based economy.

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