Effect of Gamma Irradiation on Mechanical Properties of Natural Fibers Reinforced Hybrid Composites

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Abstract

Composite materials have fully established themselves as workable engineering materials and are now quite common place around the world. The use of natural fibers as reinforcement in polymeric composites for technical application has been a research subject of scientist. Among several natural fibers, Pineapple leaf fiber (PALF) is one that has good potential as reinforcement in polymer composite. Jute fibers biodegradability, low cost and moderate mechanical properties make it as a preferable reinforcement material in the development of polymer matrix composites. Extracted PALF and Jute fibers were then subjected to chemical treatment and dried in hot air oven to hinder the water content. In the present work the composite specimens are prepared by using Bisphenol-A (BPA) as a matrix and the short PALF/Jute fibers with length of 9mm and 30% volume fraction as reinforcement. Randomly oriented Hybrid (PALF and Jute) fibers were reinforced with Bisphenol-A matrix and composites have been developed by traditional hand lay-up technique. These test samples were exposed to different gamma radiation dose in the range of 1 to 20 kGy. Then mechanical properties of hybrid composites were tested using computerized UTM machine as per the ASTM standards. The hybrid composites irradiated with 5 kGy radiation dosage delivered the best results. Water absorption behavior of the hybrid composites was also explored. Scanning Electron Microscope (SEM) has been utilized to understand the mechanical behavior of developed hybrid composites.
Keywords: Pineapple Leaf Fibers, Jute Fibers, Chemical Treatment, Hybrid Composites, Gamma Radiation, Mechanical Properties, Morphology

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I. INTRODUCTION

Composite materials are materials 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. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter or less expensive when compared to traditional materials.

Composites made of the same reinforcing material system may not give better results as it undergoes different loading conditions during the service life. In order to solve this problem hybrid composites are the best solution for such applications. Hybrid composites are materials are made by combining two or more different types of fibers in a common matrix. Hybridization of two types of short fibers offers some advantages over the use of either of the fibers alone in a single polymer matrix. The combination of bio-fibers like kenaf, oil palm, industrial hemp, flax, jute, henequen, pineapple leaf fiber, sisal, wood and various grasses with polymer matrices from both renewable resources and non-renewable (petroleum based) to produce composite materials that are competitive with synthetic composites such as polypropylene-glass, glass epoxies, etc., is gaining attention over the last decade.

Natural fibers are plant based which are lignocellulosic in nature and composed of cellulose, hemicelluloses, lignin, pectin and waxy substances. Cellulose gives the strength, stiffness and structural stability for the fibre, and is the major framework components of the fibre. Pineapple Leaf Fiber (PALF) is one such fiber source known from a long time obtained from the leaves of pineapple. Pineapple leaves from the plantations are being wasted as they are cut after the fruits are harvested before being either composted or burnt. Additionally, burning of these beneficial agricultural wastes causes environmental pollution. Jute is abundantly available in countries like India, Bangladesh, and China etc. Jute possesses high toughness and aspect ratio in comparison to other natural fibres. Jute is a ligno-cellulosic fiber and its composites have high impact strength with moderate tensile and flexural properties compared to other natural fibres. Over the past decade, cellulosic fillers have been of greater interest, since they give improved mechanical properties to composite material compared to those containing non-fibrous fillers.

Thermosetting resins such as epoxy, polyester, polyurethane, phenolic, etc. are commonly used today in natural fiber composites, in which composites requiring higher performance applications. They provide sufficient mechanical properties, in particular stiffness and strength at acceptably low price levels. Bisphenol-A (BPA) resin is a thermoset resin with good thermal and environmental stability, high strength and wears resistance. This combination of properties permits the application of BPA in polymer-based heavy duty sliding bearings. For these purposes, BPA usually is compounded with reinforcements like glass or carbon fibers and ceramic .mineral oxides and inorganic fillers. The use of fibers in polymeric composites helps to improve tensile and compressive strengths, toughness (including abrasion), dimensional stability, thermal stability, and other properties.

Gamma Irradiation is the process by which an object is exposed to gamma radiation. In order to increase the interfacial bonding strength between the matrix and fiber, the hybrid composites were irradiated with gamma rays of varying dosages in the presence of air. The dosage given to the specimen is expressed in terms of kilo Gray (kGy).

II. MATERIALS AND METHOLOGY

Pineapple Leaf Fiber (PALF) is one such fiber source known from a long time obtained from the leaves of pineapple plant (Ananas cosmosus) from the family of Bromeliaceous. Jute plants belong to the Tiliaceae family. Jute fiber is being used as a reinforcement material in the development of reinforced plastics for various engineering applications. This Jute fiber has advantage such as biodegradability, low cost, and moderate mechanical properties make it as a preferable reinforcement material in the development of polymer matrix composites.

Bisphenol-A (BPA) is an organic compound which belongs to the group of diphenyl methane derivatives and Bisphenol [6]. The chemical formula for BPA is $(CH_3)_2C\ (C_6H_4OH)_2$. It is used to make certain plastics and epoxy resins; it has been in commercial use since 1957 [6].

A. Materials

Pineapple Leaf fibers were purchased from Shree Lakshmi Chemicals Ltd., Andhra Pradesh. Jute fibers were obtained from the Chandra prakash & Co, Jaipur, Rajasthan and Bisphenol-A resin was supplied from Balaji fabrications, Mysuru, Karnataka.

B. Chemical Treatment to Fibers

Extracted pineapple leaf and jute fibers were subjected to alkali treatment or mercerization using sodium hydroxide (NaOH) is the most commonly used treatment for bleaching and cleaning the surface of natural fibers and to produce high-quality fibers. Modifying natural fibers with alkali treatment has greatly improved the mechanical properties of the resultant composites. Firstly, 5% NaOH solution was prepared using sodium hydroxide pellets and distilled water. Then both fibers were dipped in the NaOH solution for 1hour separately. After 1 hour, fibers were washed with 1% HCl solution to neutralize. Finally, it is washed with distilled water. Fibers were then kept in hot air oven for 3 hours at 65-70°c to hinder the water content. Then fibers were chopped to required fiber length.

C. Manufacturing of Composite

For composite fabrication, a polypropylene (PP) mould having dimensions of 190 X 140 X 5 mm3 is used. The mass fraction for the prepared mould is calculated using equation of volume fraction of the fiber and density of fiber. The mould was first cleaned with wax so that the laminate easily comes out of the die after hardening. Then around 15 to 20 ml of promoter and accelerator are added to Bisphenol and the color of the resin changes from pale yellow to dark yellow with the addition of these two agents. The laminates of 9mm fibers lengths of short PALF/Jute are prepared using hand layup method. This method of manufacturing is a relatively simple method compared to other methods like vacuum bag molding, resin transfer molding, autoclave molding etc. Fig 2.1 shows the final hybrid composite laminate in the polypropylene (PP) mould.

Fig. 2.1: Final Laminate

The mass fraction for the prepared mould and for desired volume fraction of fiber is calculated using following equations:
Volume fraction of fiber (V_F) = v_f / v_c ...(1)
Density of the fiber (ρ) = m_f / v_f …(2)
Where, v_f = Volume of the fiber, v_c= Volume of the composite, m_f = Mass fraction of the fiber.

D. Gamma Irradiation

The test specimens of ASTM standards were irradiated using cobalt-60 source accelerator at a dose range of 1 to 20 kGy in the sequence of 1, 2, 3, 5, 10, 15 and 20 kGy. All the samples were irradiated at room temperature. Gamma irradiation was carried out at Microtrol Sterilization Service Private Limited India, Bengaluru.

E. Determination of Mechanical Properties

The mechanical testing has been done on the composite laminate specimens as per the guidelines given in ASTM standards for the respective tests. The mechanical tests are usually performed to identify the strength parameters of any kind of materials considered or prepared under the studies. All the tests were carried out in BRAKES INDIA LTD, Mysore.

1) Tensile Test:

The most important single indication of strength in a material is the tensile test. In this test, the most properties can be represented by Young's modulus and tensile strength. Tensile tests were performed according to ASTM D 638-01standard using computerized universal testing machine of JJ Lloyd universal testing machine with load cell of 1kN and using crosshead speed of 5 mm/min at room temperature. The dimensions of the test specimens were 165 mm × 13 mm × 5 mm. The specimen was placed in the grip of the tensile testing machine and the test is performed by applying tension until it undergoes fracture.

2) Flexural Test:

Flexural Test is the capacity of a material to withstand bending forces which is applied perpendicular to its longitudinal axis. The flexural test is performed using the same computerized testing machine as per the ASTM: D790 standards at the same cross-head speed. In this test, the most properties can be represented by flexural strength and flexural modulus. Specimens of 125 mm length and 14.5 mm width were cut and placed between two points or supports of the apparatus and initiating a load using a third point or center. The span length was kept at 50mm. This test determines the behavior of the specimen when it is subjected to simple beam loading. The basic relationship to determine flexural or bending strength is,

$$\text{Bending Strength(BS)} = 3PL/ 2bd^2 \quad (1)$$

Where, P= maximum load (kN)
L= span length (mm)
b= width of the specimen (mm)
t= thickness (mm)

3) Impact Test:

Impact strength is defined as the ability of a material to resist the fracture under stress applied at a high speed. Impact strength test were performed in the computer integrated IZODE test machine. The impact specimen are prepared according to the required dimension following the ASTM-D256 standard. The dimensions of the test specimens were 63.5 mm × 12.5 mm × 5 mm. The V-notch is made at the distance of 30 mm from the top at a depth of 2.5mm.The basic relationship to determine impact strength is,

$$I = K/A \quad (2)$$

Where, I= Impact Stength (KJ/m^2)
K= Energy required to break the specimen (KJ)
A= Cross section area (m^2)

F. Water Absorption Behavior:

Composite samples (unirradiated and gamma irradiated) were immersed in glass beaker having distilled water at room temperature for different time intervals. Before immersion into the glass beaker, sample weight was recorded. At regular time intervals, samples were taken out from the glass beaker and wiped smoothly with tissue paper and then weighed instantly. Percentage of water uptake was then determined using the formula,

$$W_{up}(\%) = \frac{W_t - W_o}{W_o} * 100\%$$

Where, W_{up}= Percentage of Water Uptake
W_t = Sample weight after immersion in water
W_o = Sample weight before immersion in water

G. Scanning Electron Microscope Analysis:

Morphological observations of tensile fracture surface of hybrid composites with unirradiated and gamma irradiated (5kGy) specimens were made at room temperature using S2400 Scanning Electron Microscope (SEM) model. The morphological properties show the variation in the mechanical properties through phase information changes of hybrid composite specimens.

III. RESULTS AND DISCUSSIONS

Table 3.1 and 3.2 shows the experimental values of mechanical properties for bisphenol-A matrix and the experimental values of the entire test conducted to hybrid composites for different gamma irradiation dosages.

Table - 3.1
Mechanical Properties of Bisphenol-A Matrix Material

Properties	*Values*
Tensile Strength (MPa)	*14.1*
Tensile Modulus (MPa)	*1470.42*
Flexural Strength (MPa)	*33*
Flexural Modulus (MPa)	*1330.01*
Impact Strength (KJ/m^2)	*2.01*

Table - 3.2
Experimental Values of the Entire Test Conducted to Hybrid Composites for different Gamma Irradiation Dosages

Sl No.	*Irradiation Dosages*		*Tensile Properties*			*Flexural Properties*		*Impact Strength (KJ/m^2)*
		Maximum Load (kN)	*Tensile Strength (MPa)*	*Young's Modulus (MPa)*	*Maximum Load (kN)*	*Flexural Strength (MPa)*	*Flexural Modulus (MPa)*	
1	*0 kGy (Unirradiated)*	*1.3243*	*20.3738*	*2869.19*	*242.13*	*47.3835*	*2545.43*	*2.482*
2	*1 kGy*	*1.3698*	*21.0737*	*2967.76*	*248.69*	*48.6673*	*2608.14*	*2.571*
3	*2 kGy*	*1.4129*	*21.7369*	*3081.12*	*255.15*	*49.9315*	*2788.56*	*2.696*
4	*3 kGy*	*1.4315*	*22.0284*	*3183.01*	*272.08*	*53.2446*	*2924.08*	*2.753*
5	*5 kGy*	*1.5544*	*23.9147*	*3279.32*	*289.77*	*56.7064*	*3166.67*	*2.976*
6	*10 kGy*	*1.3821*	*21.2646*	*2951.30*	*266.98*	*52.2426*	*2819.54*	*2.719*
7	*15 kGy*	*1.3470*	*20.7245*	*2810.25*	*251.62*	*49.2407*	*2714.74*	*2.523*
8	*20 kGy*	*1.2268*	*18.8744*	*2406.67*	*231.72*	*45.1506*	*2375.82*	*2.357*

A. Mechanical Properties:

The hybrid composite is subjected to gamma irradiation with cobalt-60 source in the presence of air for different dosage to know their effect on mechanical properties. The gamma radiation dosage given to the hybrid composites are 1, 2, 3, 5, 10, 15 and 20 kGy.

1) Tensile Properties:

The experimental results tabulated in Table 3.1 and 3.2 indicates that the tensile strength and young's modulus of the matrix resin material (Bisphenol-A) increases when the fibers are reinforced. The tensile strength of the bare matrix material increases by 45% from 14.1 MPa to 20.3738 MPa after the reinforcement of jute and PALF hybrid fibers. The young's modulus of the resin material approximately increases by 95% from 1470.42 MPa to 2869.19 MPa after the reinforcement of fibers. The increase of tensile strength and modulus of elasticity actually means that the bisphenol-A resin with fiber reinforcement is stiff and hence can endure higher stress at the same strain portion.

Fig 3.1 shows the variation of tensile strength and young's modulus of the hybrid composites respectively for various dosages of gamma irradiation. With the gamma radiation dose of 1 kGy the value of tensile properties shows slight improvement over that of unirradiated hybrid composite.

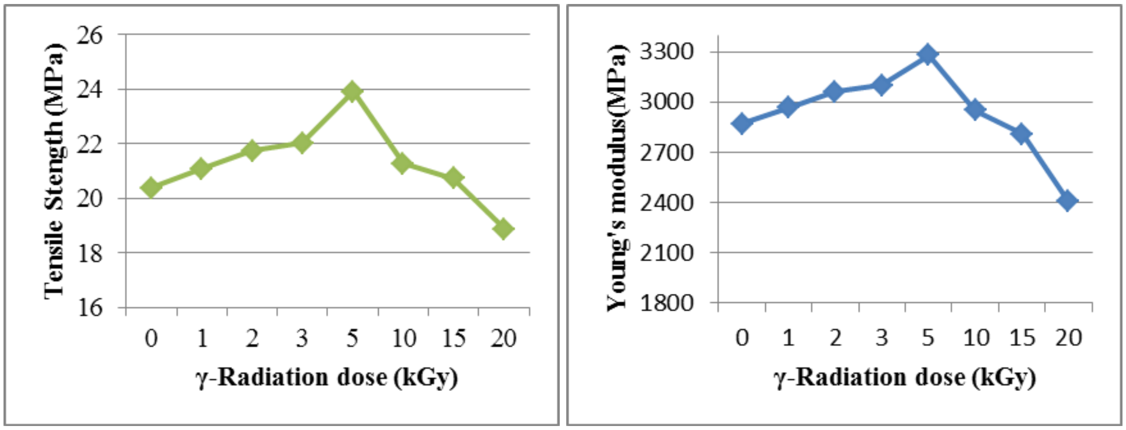


Fig. 3.1: Tensile Strength, Young's Modulus of Hybrid Composites for Varying Gamma Radiation dosages

It is observed from the figures that, with the increase in gamma radiation dose up to 5 kGy the value of tensile strength and young's modulus shows an improvement due to cross-linking. Moisture from the hybrid composite may also be removed by gamma irradiation. This will contributed to better adhesion between matrix and fiber. Cross-linking is the phenomenon where molecules will join together to form larger molecules, which results in the improvement of tensile properties.

Further increase in the radiation dose decreases the values of tensile strength and young's modulus due to phenomenon namely, chain scission. In chain scission phenomenon, molecules will break into smaller fragments which results in the decrease of tensile properties. The highest value of tensile strength and young's modulus obtained for the gamma radiation dosage of 5 kGy is reported to be 23.9147 MPa and 3279.32 MPa respectively. Thus a gamma radiation dosage of 5 kGy is considered as the optimum dose for better tensile properties. The stress-strain curve obtained for 5 kGy gamma irradiated composite is as shown in Fig 3.2.

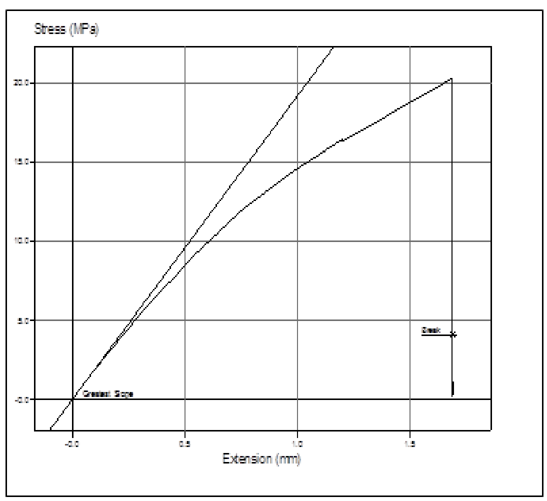


Fig. 3.2: Stress-Strain Curve for 5 Kgy Gamma Irradiated Hybrid Composite

It is seen that tensile strength of hybrid composites increases moderately from the value of 20.3738 MPa (at 0 kGy or unirradiated) to the maximum value of 23.9147 MPa (at 5kGy) of irradiation. Approximately, at an irradiation dosage of 5 kGy, the tensile strength and young's modulus improves by 17% and 15% respectively over that of unirradiated specimens. It can be observed from the table 3.2 that, tensile properties of the specimen at 20 kGy irradiation decreases over that of unirradiated composites. The reason for the loss of tensile properties at higher radiation dose of 20 kGy might be due to severe degradation of the polymer molecule.

2) Flexural Properties:

The experimental results tabulated in Table 3.1and 3.2 indicates that the flexural strength and flexural modulus of the matrix resin material (Bisphenol-A) increases when the fibers are reinforced. The flexural strength of the bare matrix material increases by 44% from 33.02 MPa to 47.3835 MPa after the reinforcement of jute and PALF hybrid fibers. The young's modulus of the resin material approximately increases by 91% from 1330.01 MPa to 2545.43 MPa after the reinforcement of fibers.

The increase of flexural strength and flexural modulus actually means that the bisphenol-A resin with fiber reinforcement is stiff and hence can endure higher stress at the same strain portion. Fig 3.3 shows the variation of flexural strength and flexural modulus of the hybrid composites respectively for various dosages of gamma irradiation. With the gamma radiation dose of 1 kGy the value of flexural properties shows slight improvement over that of unirradiated hybrid composites.

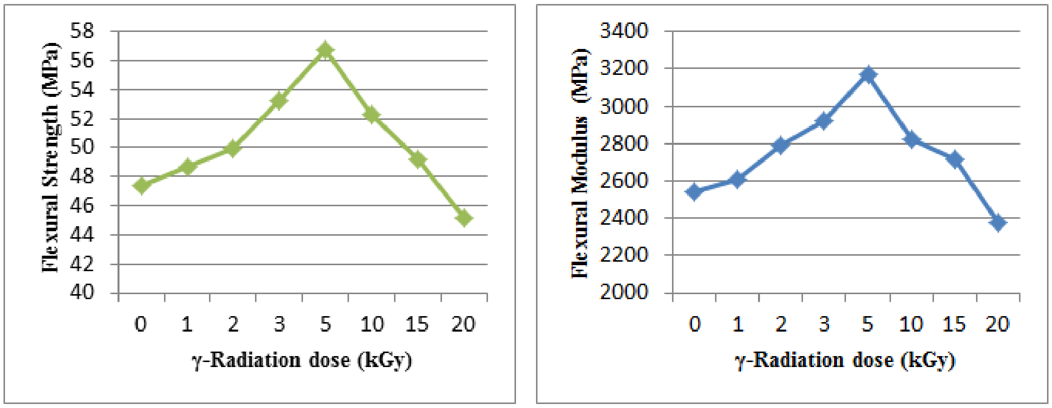


Fig. 3.3: Flexural Strength, Flexural Modulus of Hybrid Composites For Varying Gamma Radiation Dosages

It is observed from the figures that, with the increase in gamma radiation dose up to 5 kGy the value of flexural strength and flexural modulus shows an improvement due to cross-linking and hence better fiber matrix adhesion. Further increase in the radiation dose decreases the values of flexural strength and flexural modulus due to phenomenon namely, chain scission. The highest value of flexural strength and flexural modulus obtained for the gamma radiation dosage of 5 kGy is reported to be 56.7064 MPa and 3166.67 MPa respectively. Thus a gamma radiation dosage of 5 kGy is considered as the optimum dose for better flexural properties. The maximum bending stress curve obtained for 5 kGy gamma radiation dose is shown in Fig 3.4.

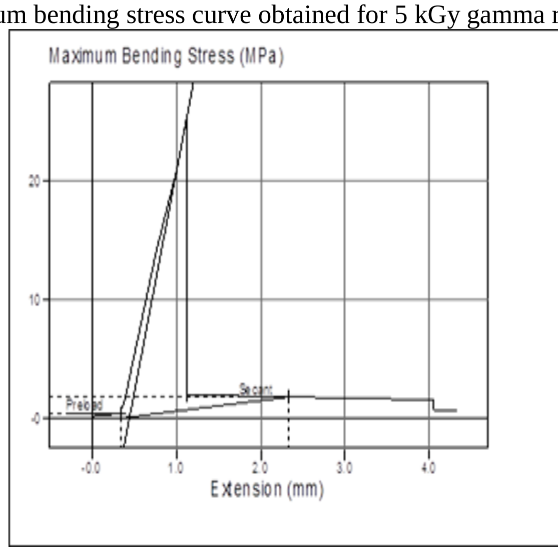


Fig. 3.4: Maximum Bending Stress Curve For 5 Kgy Radiation Dose

It is seen that flexural strength of hybrid composites increases moderately from the value of 33.02 MPa (at 0 kGy or unirradiated) to the maximum value of 56.7064 MPa (at 5kGy) of irradiation. Approximately, at a gamma irradiation dosage of 5 kGy, the flexural strength and flexural modulus improves by 19% and 23% respectively over that of unirradiated specimens. It can be observed from the table 3.2 that, flexural properties of the specimen at 20 kGy irradiation decreases over that of unirradiated composites. The reason for the loss of flexural properties at higher radiation dose of 20 kGy might be due to severe degradation of the polymer molecule.

3) Impact Properties:

It is noted from the table 3.2 that, the impact strength of the un-reinforced bisphenol-A resin is increasing significantly after reinforcement of hybrid fibers from 2.01 KJ/m^2 to 2.482 KJ/m^2. The value of impact strength increases approximately by 23.5%. It can be observed from figure 3.5 that, with gamma irradiation dose of 1 kGy there is slight improvement over that of unirradiated hybrid composite.

Figure 3.5 shows the variation of the impact strength of hybrid composites for varying gamma radiation dosages. It is observed that, gamma irradiated hybrid composite is showing improvement in impact strength up to 5 kGy radiation dose due to crosslinking phenomenon. As the radiation dose increases from 5 kGy, the value of the impact strength reduces on exposure to intense gamma radiation dose of (10, 15 and 20 kGy) due to chain scission phenomenon.

The highest value of Izod impact strength at a radiation dosage of 5 kGy radiation is reported to be 2.976 KJ/m^2, an improvement of 20% approximately over that of unirradiated specimen. Thus, 5 kGy of gamma radiation dose is considered to be the optimum dosage value to obtain higher impact strength values. At 20 kGy of gamma radiation dose severe polymer degradation occurs resulting in impact strength value less than the value obtained for unirradiated composites. It is noted that adhesion between matrix and fiber is better at 5 kGy of γ-radiation dose.

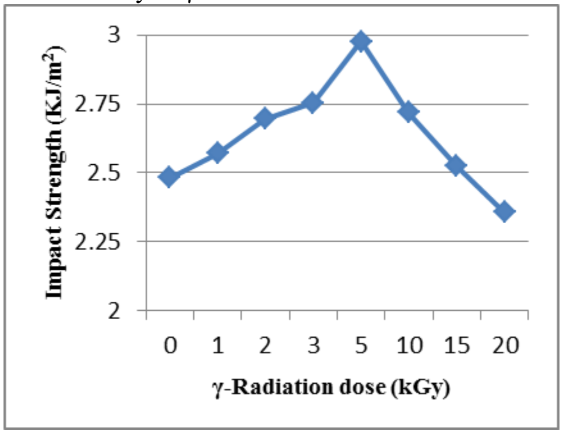


Fig. 3.5: Impact Strength of Hybrid Composites for Varying Gamma Radiation Dosages

B. Water Absorption Behavior:

To determine the water absorptivity of unirradiated and the gamma irradiated hybrid composites this test is most important. The percentage water uptake value of the hybrid composites are plotted against the immersion time is as shown in Fig 3.6.

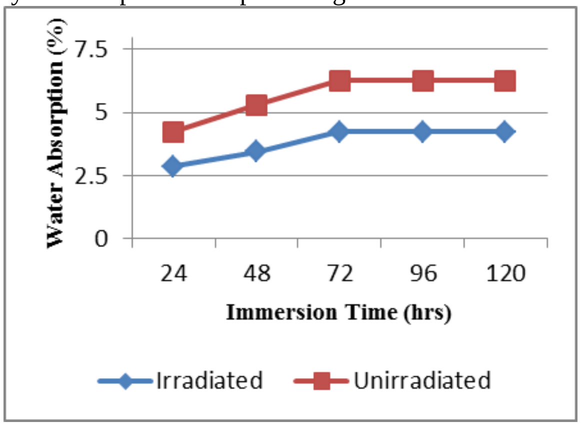


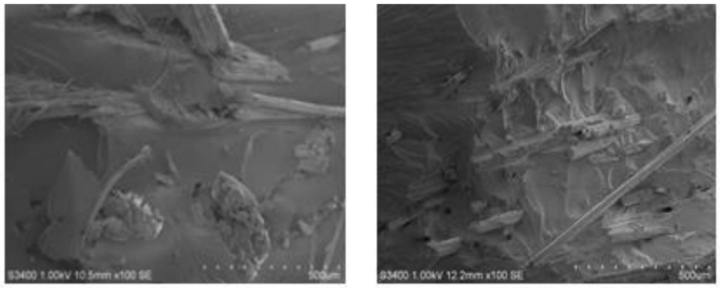
Fig. 3.6: Water Absorption Behavior of Hybrid Composites based on Immersion Time

The percentage of water uptake of the composites depends mainly on water uptake properties of hybrid fibers and degree of matrix-fiber adhesion. Water absorption phenomenon can be elaborated on the basis of hydro-d-cellulose glucose cellulose structure. Natural fibers containing hydroxyl (–OH) group in their chemical composition has the tendency to absorb water quickly. Jute and PALF fiber each contain three hydroxyl groups in their chemical composition respectively.

It was observed that unirradiated samples attained highest water absorption of 4.2% for 72 hours of immersion time whereas, water uptake of gamma treated composite are about 2% for 72 hours of immersion time. It was also shown that gamma irradiation of the hybrid composites decreased the water uptake capacity over that of unirradiated composites. Gamma irradiated composites had better matrix fiber adhesion which may be responsible for lower tendency of water uptake than that of unirradiated composites. The decrease in water absorption behavior of the gamma irradiated hybrid composites credited to the fact that gamma radiation decreased the hydroxyl groups as well as increased crystalline region through crosslinking phenomenon which sequentially decreases the amorphous regions [13].

C. Morphological Analysis:

Scanning electron microscope images are analyzed for better deductions of the reasons for failure and reduction in mechanical strength of the hybrid composites. From fig 3.7 (a) it can be observed that fiber pull-out is quite higher compared to that of gamma irradiated with 5kGy, which indicates that de-bonding takes place between fiber and matrix material which results in the decrease of tensile properties. Fig 3.7 (b) shows fracture surface with less fiber pull-out indicates compatibility between fiber and matrix is better resulting in improved tensile properties of gamma irradiated hybrid composites.



3.7 (a) 3.7 (b)

Fig. 3.7: SEM Micrographs of Tensile Fractured Surfaces for Hybrid Composites;
(A) Unirradiated (B) Gamma Irradiated With 5 Kgy Radiation Dose.

IV. CONCLUSION

The objective of the present work is to study the gamma irradiation effect on mechanical properties of short jute/pineapple leaf fibers reinforced Bisphenol-A composites. The Pineapple leaf fibers and Jute fibers were extracted by either mechanical means or by retting the leaves in the water. It was then chemically treated to hinder the water content. Chemically treated fibers were chopped down to required 9mm fiber length. Then preparation of composite laminates is made owing to 30:70 fibers to matrix percentage. The fiber to matrix percentage is calculated using the rule of mixtures and relatively the specimens are prepared using hand lay-up technique. After forming the hybrid composite laminate, samples were prepared for tensile test (ASTM D638), flexural test (ASTM D790) and impact test (ASTM D256). This test samples were then exposed to different gamma irradiation dosages with cobalt-60 source in the presence of air to know their effect on mechanical behavior of hybrid composites. From this study several conclusions are drawn,

1) The tensile properties, impact strength and flexural properties of Jute/PALF fibers hybrid polymer composites increase with reinforcement of fibers over that of the bare matrix material.
2) Gamma Irradiation is a significant way to enhance the mechanical properties of the natural fibers reinforced hybrid composites.
3) Gamma Irradiation dosage of 5 kGy is reported as the optimal dosage to obtain better mechanical properties of Jute/PALF fibers hybrid polymer composites.
4) The Gamma irradiation of the hybrid composites decreased the water uptake capacity.
5) Gamma irradiation improved the interfacial adhesion between matrix and fibers than that of unirradiated composites.

ACKNOWLEDGEMENTS

The authors are thankful to Mr. Ranganath, Mr. Gee, Microtrol Sterlisation Services Pvt. Ltd, Bommasandra-Jigani Link Road Industrial Area, Bengaluru for their help in conducting experiments.

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