Masudur Rahman *et al. Fash Text (2018) 5:28*
https://doi.org/10.1186/s40691-018-0148-y

Fashion and Textiles

RESEARCH

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Evaluating the performance of gamma irradiated okra fiber reinforced polypropylene (PP) composites: comparative study with jute/PP

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Abstract

In this study, two bast fibers such as okra and jute were selected to manufacture composites taking polypropylene (PP) as matrix material by means of compression molding technique with maintaining 40% fiber content on the total weight of the composites. Investigation was done on tensile properties such as tensile strength (TS), tensile modulus (TM), elongation at break (EB%), bending properties such as bending strength (BS), bending modulus (BM) and impact properties like impact strength (IS) and hardness (Shore-A) of the composites. From analyzed data, it was found that Okra/PP composites showed very competitive mechanical properties to Jute/PP composites. Non-irradiated okra composite showed the value of TS, TM, BS, BM, IS and hardness to be 32.2 MPa, 602 MPa, 55.6 MPa, 3.6 GPa, 19.54 kJ/m^2 and 95 (Shore-A), respectively, whereas that value for non-irradiated jute composite was 35.5 MPa, 629 MPa, 71.5 MPa, 4.5 GPa, 21.48 kJ/m^2 and 96 (Shore-A), respectively. The composite samples were exposed to different intensities of gamma radiation (250–1000 krad) at a dose rate of 330 krad/h and changes in mechanical properties were examined. Both irradiated composites (500 krad) showed significant improvement of mechanical properties compared to that of the non-irradiated composites. Maximum TS, TM, BS, BM and IS value were found to be 41.9 MPa, 685 MPa, 72 MPa, 4.7 GPa and 22.6 kJ/m^2, respectively for irradiated okra composite and 45.3 MPa, 717 MPa, 88 MPa, 6.7 GPa and 24.3 kJ/m^2, respectively for irradiated jute composite. Fourier transform infrared spectroscopy was used to identify the surface groups of the composites. Water absorption, degradation behavior of the composites under soil and heat medium were also performed. Degradation tests revealed that okra composite retained its original mechanical properties higher than that of jute composite. The morphology of the composites was inspected by scanning electron microscope.

Keywords: Okra fiber, Jute fiber, Composites, Polypropylene, Mechanical properties, Gamma radiation

Introduction

Nowadays polymer composites are widely used in different diversified fields because of their excellent and unique combination of physical and mechanical properties and they are extensively using in the civil constructions, chemical equipment and machinery constructions, electrical and electronic equipment, automobile and marine industries, aircraft manufacturing and many more (Islam et al. 2009; Jawaid et al. 2011; John and Naidu 2004; Karina et al. 2008; Khalil et al. 2007; Khan et al. 2009; Rajulu and Devi 2007; Saba et al. 2015). A lot of research works have been done on fiber reinforced composites with the synthetic matrix and synthetic reinforcements like glass, carbon, nylon and Kevlar fibers (Gowda et al. 1999). Synthetic fiber reinforced thermoplastic composites are dominating over natural fiber reinforced composites due to their improved strength, stability, corrosion and moisture resistance properties. The problem of using synthetic fiber reinforced composites is that the fibers are not biodegradable (Miah et al. 2005; Mishra et al. 2004; Mohanty et al. 2000). Due to increasing environmental consciousness, composites made of lingo-cellulosic materials as reinforcing fiber and thermoplastic polymers as matrices are exploring day by day (Rahman et al. 2008).

Natural fibers have several advantages; for example, they have low cost, acceptable strength properties, reduced energy consumption, recyclable, biodegradable and cause no skin irritation (Bullions et al. 2004; Cantero et al. 2003; Joseph et al. 2002; Mohanty et al. 2000; Zaman et al. 2013). Among all the natural fibers, jute has appealed worldwide attention as a potential reinforcement of polymer composite because of its inherent properties such as high tensile strength, low density, inexpensive and abundantly available in tropical countries (Haydaruzzaman et al. 2010; Islam et al. 2009; Khan et al. 1999). On the other hand Okra bahmia (*Abelmoschus esculentus*) is a monocotyledon herbaceous plant under the family of Malvaceae, present mainly in Bangladesh and also in some other tropical countries in the world. Fibers can be extracted from the outer cell layers of the stem (Fortunati et al. 2013a, b). Presently the fiber has no economic value as the plant is subjected to combustion. In practice, okra mucilage can be used as a moistness absorber (Gögus and Maskan 1999). And the mucilage of okra fiber can be applicable for the production of decomposable polymer materials with proper grafting process (Mishra and Pal 2007). The composition of okra fiber is hemicellulose (15–20%), α-cellulose (60–70%), lignin (5–10%) and pectin (3–5%). The fiber exhibited improved tenacity (40.1–60.5 MPa) and higher elongation at break (3–5%) also (Alam and Khan 2007; Khan et al. 2009a).

Although several advantages, cellulosic fibers endure the drawback of nonresistance to high temperature and proneness to moisture absorption. Hydroxyl groups present in the cellulose create various hydrogen bonds and make the cellulosic fibers hydrophilic in nature (Sawpan et al. 2003). The composites prepared with nonpolar thermoplastic matrix and hydrophilic natural fiber result in reduced mechanical properties due to the poor affinity between the plastic material and fiber (Hassan et al. 2005a, b). The mechanical properties of the composites can be enhanced by modification of natural reinforcing fibers by various physical and chemical methods such as alkali/mercerization, monomer grafting under UV and gamma radiation (Zaman et al. 2010). Amongst those gamma radiation is a very effective way of tailoring the surface properties of fibers, composites and polymers. Gamma radiation is known to deposit energy in solid cellulose by

Compton scattering and the rapid localization of energy within molecules produced trapped macro cellulosic radicals. The radicals thus created are responsible for changing the physical, chemical and biological properties of cellulose fibers, polymers and composites (Ali et al. 1997; Li et al. 2005, 2010; Wan et al. 2005). Variations of properties of polymeric materials caused by gamma radiation have been mainly attributed to chemical reactions, like chain scission and/or creation of cross-links (Davenas et al. 2002; Startsev et al. 1999).

Polypropylene (PP) is widely used in thermoplastic composites because it possesses several outstanding properties like low density, high softening point, good flux life, good surface hardness, scratch resistance, very good abrasion resistance, low moisture pickup and high impact strength (Czvikovszky 1995; Khan et al. 2001).

Several works have been carried out on okra fiber reinforced composites. Srinivasababu et al. (2009), De Rosa et al. (2010) and Onyedum et al. (2015) investigations shown that okra fiber can be used as reinforcement in composite materials. But no work has been reported the role of gamma radiation on physical and mechanical properties of okra fiber composites.

In Bangladesh, okra plant is considered as an agricultural wastage product after collecting vegetable. The chemical composition of okra fiber is similar to other commercial bast fiber like jute, which is commonly used in the composite material in Bangladesh also in world wide. But the production cost of jute is higher than other bast fibers. So, in the present investigation, an effort has been exerted to establish okra fiber as a potential reinforcement in the thermoplastic composite material to increase the use and commercial value of the fiber.

The study was designed to fabricate and investigate the comparative mechanical properties of Okra/PP and Jute/PP composites. The mechanical properties such as tensile strength, tensile modulus, bending strength, bending modulus, impact strength were examined for both non-irradiated and irradiated composites and the values were compared.

Methods

Materials

Okra plant has been collected from Gazipur District (Bangladesh). About 3 months old and around 2.5 m high plants were collected. After collection, the middle portion of the stems was separated and then dipped under water for retting. Fiber geometry and mechanical properties of fibers strongly depend on stem age (Ayre et al. 2009). The stems were degraded sufficiently within 15–20 days to allow the collection of fibers. The degraded stems were washed several times using distilled water and then the fibers were obtained. They were dried in open air and reserved in fresh container afterward (Fortunati et al. 2013a, b; Sathishkumar et al. 2013). Jute fibers (Tossa) were supplied by Bangladesh Jute Research Institute (BJRI), Dhaka. Polypropylene (trade name: Cosmoplene) was purchased from Polyolefin Company, Private Ltd., Singapore. Figure 1 shows the images of fibers used in this experiment.

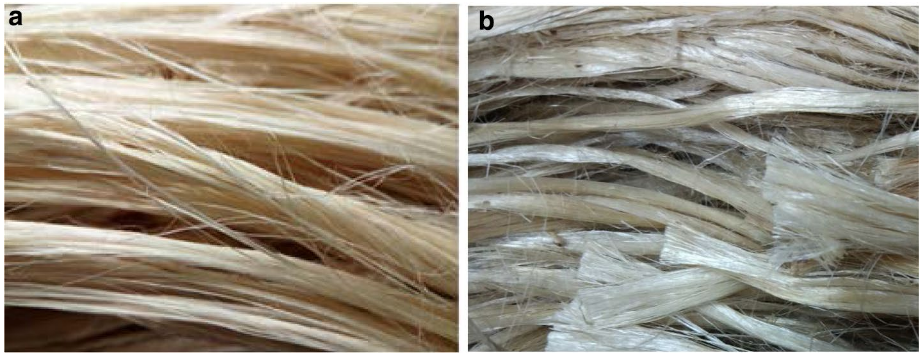

Fig. 1 Fibers used in this study, Okra fiber (**a**) and Jute fiber (**b**)

Composite fabrication

At first polypropylene sheets were prepared from granules. The pre-weighted granules were heated for 5 min at 190 °C temperature by placing them in between two steel plates in a compression molding machine. The model of the machine was 3856, Carver Incorporation, USA. Cooling was done another compression molding machine of the same model for 5–7 min at room temperature using 5 metric ton pressure. The resultant polypropylene sheets were cut to the desired size (12 cm × 12 cm) for composite manufacturing. Okra and jute fibers were cut into the length of 20–25 mm. Four layers of fibers were inserted between five sheets of pre-weighted polypropylene during the fabrication of composite. The fibers were embedded randomly in between polypropylene sheets. By this way, a sandwich is formed which was then employed between two steel plates under a pressure of 5 metric ton for 5 min with keeping the temperature of 190 °C (shown in Fig. 2). The thickness of the resultant composites was kept 2 mm. Testing specimens were prepared from the composite sheet by cutting with grinding machine carefully.

Mechanical testing of the composites

Tensile strength, tensile modulus, elongation at break (%) was investigated by following the DIN 53455 standard method using a Hounsfield S series Universal Testing Machine, model: H 50 KS-0404. The cross-head speed was set 10 mm/min during testing and the gauge length was 20 mm. The geometry of the test specimen was maintained 60 mm × 15 mm × 2 mm. Bending strength and bending modulus were examined according to DIN 53452 by means of above-mentioned equipment. The test speed and span distance was 10 mm/min and 40 mm, respectively. The Charpy impact strength was performed by maintaining the standard of DIN EN ISO 179 in the un-notched, flat mode by means of a pendulum type impact testing machine (Model-3016, Germany). The hardness of the composite samples was tested by an HPE Durometer (model type 60578, Germany) according to DIN 53505 standard. The mechanical properties of unreinforced polypropylene sheet were also tested according to the above-mentioned method.

Prior to testing all the testing specimens were conditioned at 25 °C and 50% R.H for several days. All the mechanical properties of composites were tested under the similar conditions. The average value of five samples was taken as the final value of all tests.

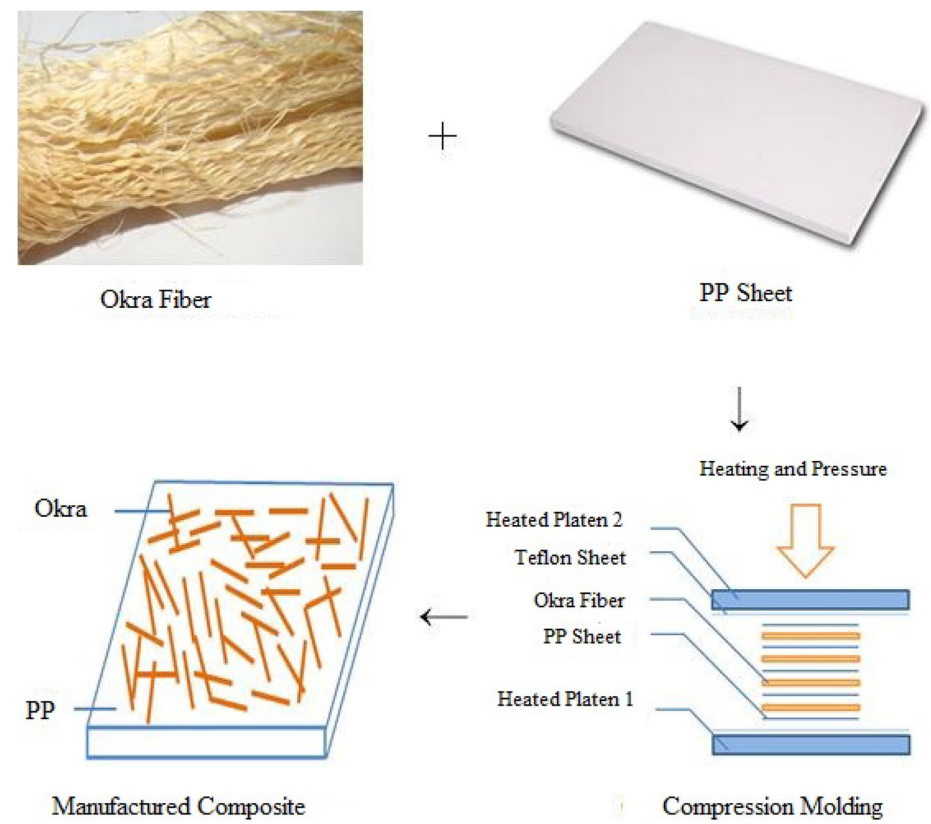

Fig. 2 Fabrication of composite by compression molding technique

Irradiation

The composite samples were exposed to irradiation for different doses (250–1000 krad) with a dose rate of 330 krad/h by using the available gamma source of Cobalt 60 (90 kCi) of the BAEC, Savar, Dhaka.

Fourier transform infrared spectroscopy analysis

In order to investigate the possible changes in the chemical composition of the composites by gamma radiation, FTIR-ATR analysis was done on the Perkin Elmer SPECTRUM BX in the range of 4000–400/cm.

Water uptake

Water absorption ability of composite samples was carried out in deionized water. The experiment was done at room temperature (25 °C) for 60 h into a glass beaker containing 100 ml water. The size of the specimens was 20 mm × 10 mm × 2 mm. The samples were dried at 105 °C in an oven before dipping, then cooling was done in a desiccator and the weight was measured. After a different soaking period, the mass of the samples was taken by withdrawing them from the beaker. Water absorption was calculated by the following formula: $W_g\% = [(W_a - W_0)/W_0] \times 100$, where W_g is the water uptake (%), W_0

denoted the mass of the specimens before dipping and W_a indicated the mass of the test samples after water treatment.

Thermal degradation test

For determination of thermal aging, a thermo stated oven was selected and the test was continued up to the time period of 30 days. Model of the instrument was Denver, AA-160. After a certain time (5 days), samples were taken out from the oven and reserved at 25 °C for 24 h for testing the tensile properties.

Soil degradation study

The composite test samples were buried in soil at 15 cm depth for the assessment of degradation behavior of the composites in soil medium. The soil should contain at least 25% moisture and the assessment was continued up to 20 weeks. After a certain time, samples were taken out from soil followed by washing with purified water and then dried for 6 h keeping the temperature of 105 °C. The samples were preserved for 24 h at room temperature for conditioning to observe the tensile behaviors.

Scanning electron microscopic analysis

SEM micrographs were taken from a scanning electron microscope (model JS 6490, Japan). Tensile fracture samples were selected for analysis of SEM. The dimension of the specimens was 2 mm × 2 mm and the experiment was done at room temperature using 20 kV acceleration voltage.

Result and discussion

Comparative studies of the mechanical properties of the composites

The mechanical properties of unreinforced PP sheet, Okra/PP (40% fiber by wt.) and Jute/PP (40% fiber by wt.) composites were investigated and compared. The results are presented in Table 1.

From Table 1, it was examined that TS, TM, EB (%), BS, BM, IS and hardness of the PP sheet was found to be 20.6, 498 MPa, 370%, 35.3 MPa, 1.9 GPa, 4.51 kJ/m^2 and 92 Shore-A, respectively. Both okra and jute composites gained a significant improvement in the mechanical properties. Both type of fibers successfully reinforced with PP matrix. The TS and TM of Okra/PP composite increased to 56 and 21%, respectively than that of unreinforced PP. It was noticed that BS, BM and IS also improved 58, 89 and 333%, respectively for okra composite over the matrix material PP. Similarly, Jute/PP composite possessed a significant improvement of TS, TM, BS, BM and IS compared to matrix PP.

Table 1 Comparative tensile, bending, impact and hardness property of unreinforced PP sheet and composites

Materials	Tensile properties			Bending properties		Impact strength	Hardness (Shore-A)
	TS (MPa)	TM (MPa)	EB (%)	BS (MPa)	BM (MPa)	IS (kJ/m^2)	
Polypropylene	20.6 ± 0.9	498 ± 8	370 ± 7	35.3 ± 1.2	1.9 ± 0.3	4.51 ± 0.2	92 ± 0.5
Okra/PP	32.2 ± 0.8	602 ± 10	9.8 ± 0.2	55.6 ± 1.1	3.6 ± 0.4	19.54 ± 0.3	95 ± 0.5
Jute/PP	35.5 ± 0.7	629 ± 7	13.4 ± 0.4	71.4 ± 1.4	4.5 ± 0.2	21.48 ± 0.4	96 ± 0.5

Jute composite showed 72% increase in TS and 26% increase in TM over that of PP. It was also reported that BS, BM and IS improved 102, 137 and 376%, respectively for jute composite than that of PP. Hardness (Shore-A) indicated that the hardness of both types of composites had almost similar properties. The maximum hardness value was found to be 96 (Shore-A) for jute composite. It was found that Okra/PP composite showed relatively reduced TS, TM, BS, BM, IS and hardness compared to Jute/PP composite.

It was revealed that the TS and TM of jute composite are improved 10 and 4% over the okra composite, respectively. On the other hand, the BS, BM and IS of the Jute/PP is improved 28, 25 and 10% higher than that of the Okra/PP. The improvement of mechanical properties of Jute/PP composite over Okra/PP composite is due to the higher strength of jute than okra fiber.

The tensile strength of composite materials is straightly depending on the strength and modulus of the reinforcing fibers, orientation and length of the fiber, fiber loading, as well as fiber-matrix interfacial adhesion. These variable factors can explain the circumstances that the mechanical properties obtained for the Okra/PP and Jute/PP composite are lower than the expected. Other reason can be tensile strength variation of PP based on molecular structure with origin.

Influence of gamma radiation on mechanical properties of the composites

The effects of gamma radiation on the mechanical properties such TS, TM, BS, BM and IS of the composites were investigated. The tensile, bending and impact properties of the composites as a function of total dose are shown in Figs. 3, 4, 5 and 6.

From Figs. 3, 4, 5 and 6, it was observed that the tensile, bending and impact properties increasing trend from 250 to 500 krad dose and after that the values decrease up to 1000 krad dose for both types of composites. The composites showed best mechanical performance at 500 krad of total gamma dose at 330 krad/h. The value

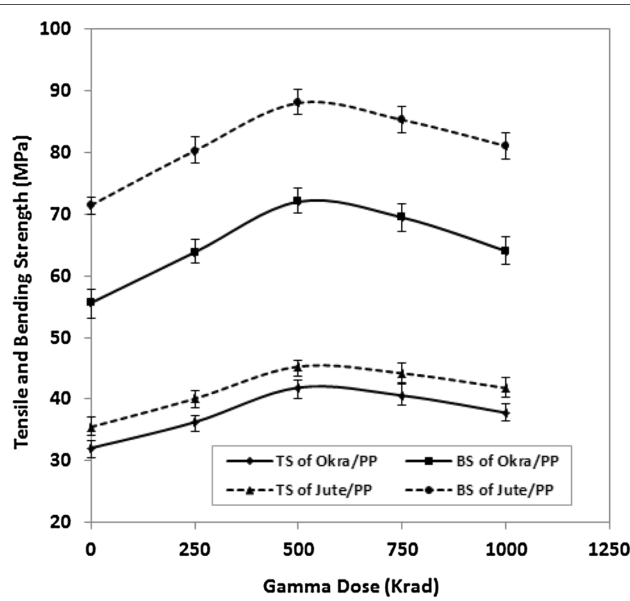

Fig. 3 Comparative tensile and bending strength of irradiated composites against radiation dosage

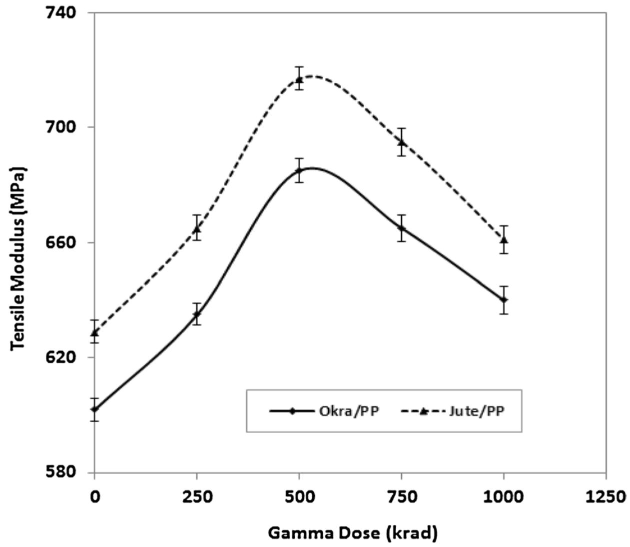

Fig. 4 Comparative tensile modulus of irradiated composites against radiation dosage

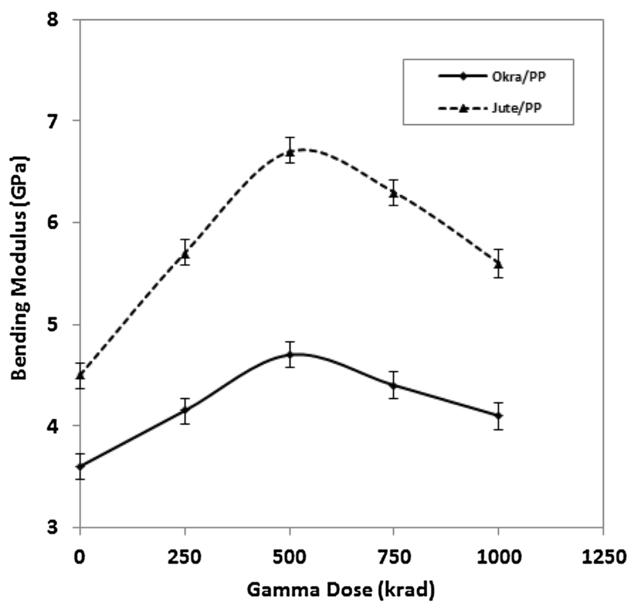

Fig. 5 Comparative bending modulus of irradiated composites against radiation dosage

of TS, TM, BS, BM and IS of Okra/PP composite were analyzed to be 41.9 MPa, 685 MPa, 72 MPa, 4.7 GPa and 22.6 kJ/m^2, respectively. For Okra/PP, about 30% increase in TS, 14% improvement in TM, 29% increment in BS, 30% increase in BM and 16% development in IS was found compared to non-irradiated sample. This is significant findings in this study. On the other hand, TS, TM, BS, BM and IS values were obtained 45.3 MPa, 717 MPa, 88 MPa, 6.7 GPa and 24.3 kJ/m^2, respectively for Jute/PP composite. For Jute/PP, about 28% improvement in TS, 14% increase in TM,

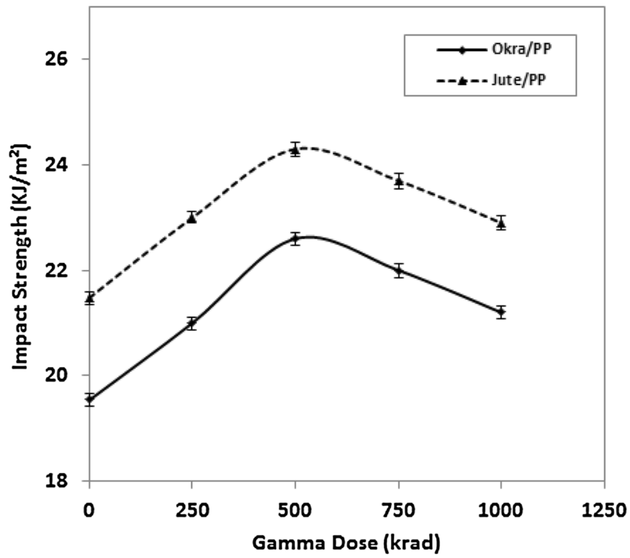

Fig. 6 Comparative Charpy impact strength of irradiated composites against radiation dosage

23% development in BS, 48% increase in BM and 13% increment in IS was found compared to the non-irradiated specimen.

Tensile, bending and impact properties of the composite are influenced by the interfacial bond strength of the PP matrix and reinforcing fiber. Gamma treatment improved interfacial bond strength by producing active sites. Subsequently, the mechanical properties of the irradiated composites were improved up to 500 krad dose due to cross-linking. It can be assumed that stress transfer between matrix and fiber was good at 500 krad leading to cracks preventing at the fiber. But above 500 krad dose, the mechanical properties of irradiated composites decreased on exposure to high energy gamma radiation which causes degradation of PP by breaking the polymer chains. Gamma irradiation affects the internal structure of the cellulose fiber and produces active sites that increase the intra-chain bond in the fiber that causes the polymeric chain to group together in a highly ordered (crystal-like) structure. The intra-chain bonds are strong and give the fiber strength. Gamma irradiation also produced active sites in the PP matrix that may contribute to better fiber-PP bonding. For these reasons, the mechanical properties of the irradiated composite increased up to 500 krad dose. Gamma radiation also alters the mechanical properties through main-chain scission (shown in Fig. 7a) and cross-linking (shown in Fig. 7b) in the amorphous region or recombination in the crystalline region. Both the process chain scission and cross-linking take place simultaneously. The degree of crystallization is affected by the amount of main chain scission induced by the different radiation doses and the rate of crystallization is related to the radiation dose and degree of cross-linking (Zaman et al. 2009). Above 500 krad dose, the mechanical properties of the composites were declined which may be related degradation of cellulose backbone due to ionizing radiation. During degradation, there will be a loss in strength due to primary bond breakage in the cellulose constituents and therefore, be related to changes taking places in the central lamella, which reduce the ultimate cell (Blouin and Arthur 1958).

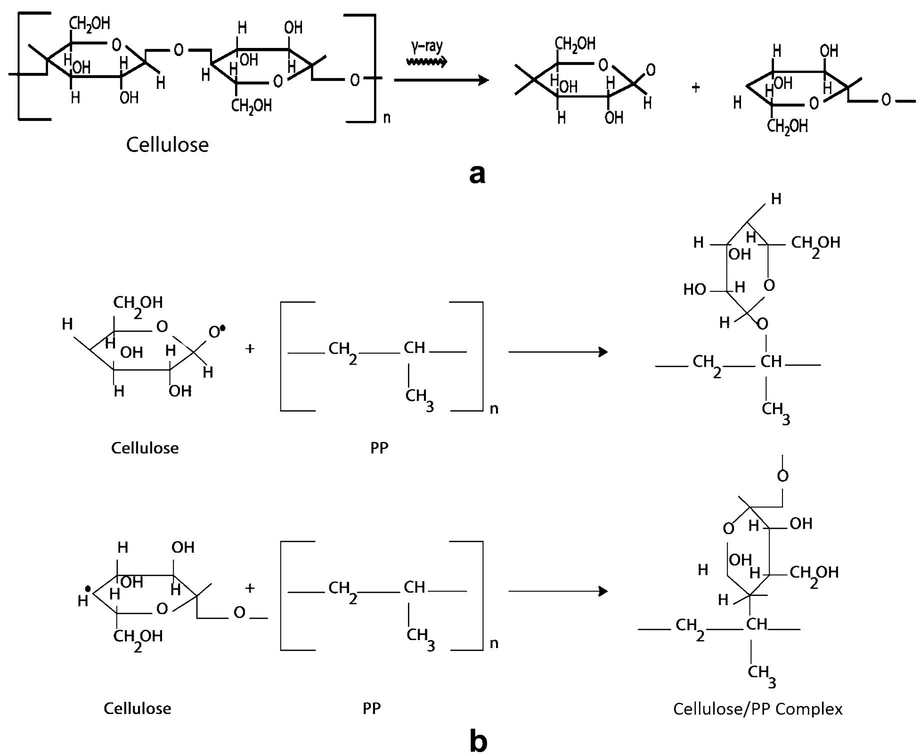

Fig. 7 **a** Chain scission mechanism of cellulose during gamma irradiation. **b** A possible cross-linking mechanism between cellulose and PP molecules

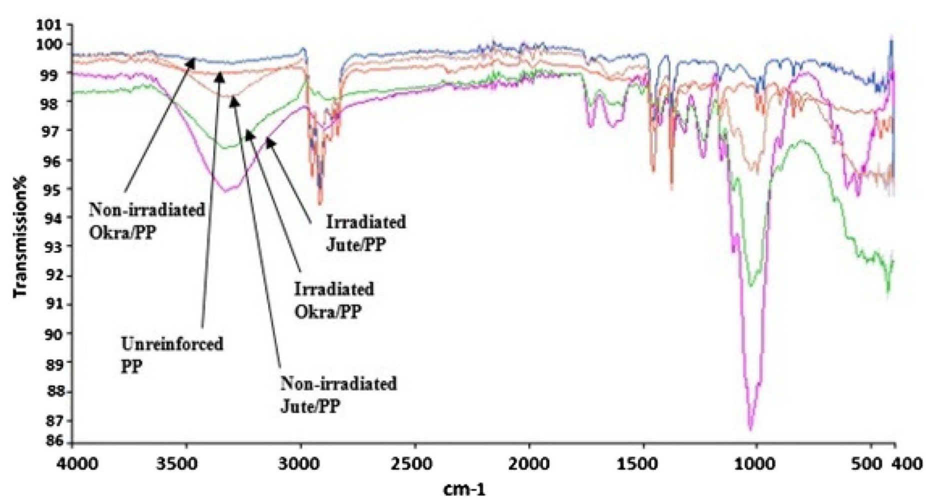

Fig. 8 FTIR-ATR spectra of unreinforced PP and composites

FTIR-ATR Analysis

To examine the presence and the type of interfacial bond in the composites, FTIR experiments were performed at the range from 4000 to 400/cm.

From Fig. 8, it is seen that the regions of interest for irradiated Jute/PP and Okra/PP are 3331 and 2916/cm which belongs to the O–H stretching. The O–H band for the irradiated composites became more pronounced and broader, probably due to the free hydroxyl groups that are now engaged in hydrogen bonding. The intensity of the C-H stretches is visible at about the peak of 1375, 1455 and 2916/cm for all samples. The C–O is stretching for irradiated Jute/PP and Okra/PP at the peak of 1029/cm due to the creation of cross-link during radiation. From FTIR-ATR spectrum of non-irradiated fiber composites show very little absorption of peaks while that of gamma treated composites showed the stretching of functional groups which could be the cause of improvement in adhesion between fiber and matrix (Matthews 1992).

Water uptake

Water uptake determines the water-swelling behavior of the samples. The results of water uptake (%) of non-irradiated and irradiated (500 krad) samples are shown in Fig. 9 against different soaking time. The water uptake values were calculated (4.2–10.2%) for non-irradiated okra composite and (5.7–12.6%) for non-irradiated jute composite at various soak time. It was observed that jute composites absorb more water than okra composites due to more hydrophilic nature of jute. The absorption rate was optimum within the first 10 h by both type of samples and then became slow. The water uptake values of gamma-irradiated (500 krad) okra composite were about (3.26–7.25%) whereas the values for jute samples were found (4.38–8.98%).

The water uptake (%) of the composites depends chiefly on water absorption properties of the reinforcing fibers and degree of matrix-fiber adhesion. Water absorption phenomenon can be explained on the basis of anhydro-D-glucose cellulose structure. Natural fibers containing hydroxyl (–OH) group in their chemical composition has the tendency to absorb water quickly. Jute and okra fiber each contain three hydroxyl groups in their chemical composition, respectively. It was observed that non-irradiated samples attained highest water absorption whereas, water uptake of gamma

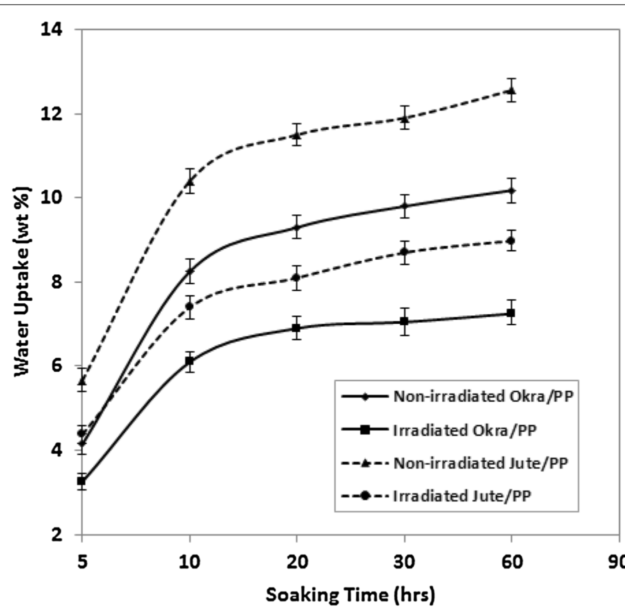

Fig. 9 Water uptake of non-irradiated and irradiated (500 krad) composites against soaking time

irradiated composites is lowest. Gamma irradiated composites had better matrix fiber adhesion which may be responsible for lower tendency of water uptake than that of non-irradiated composites. The decrease in water absorption behavior of the gamma irradiated 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. In the crystalline region, it is believed that –OH groups of adjacent cellulose molecules are mutually bonded or cross-linked. For that reason, there are no sites to hold water within crystalline regions which is not accessible for absorption of water (Islam et al. 2009; Khan et al. 2009b; Zaman et al. 2009, 2012).

Thermal degradation of the composites

The polymer has a thermal insulating property and the thermal property plays some significant role in the applications of the polymer. When a polymeric material is heated above its T_g values, its tensile property decrease significantly. Thus T_g values of a polymer are highly related to thermal and mechanical properties. Thermal aging was determined by heating composite samples at 80 °C for 30 days in an oven. The TS of these samples were measured periodically. The results are plotted against aging time and are shown in Fig. 10.

After 30 days of thermal aging, the loss of the okra and jute sample was found to be 26 and 30% of TS, respectively. It is clear that okra samples retained much of their tensile properties than the jute samples during thermal aging. It is also observed that gamma-irradiated samples showed better resistant during thermal aging. The irradiated okra and jute composites lost 22 and 26% of TS, respectively. During gamma treatment, some active sites are formed in the matrix and increased the cross-linking between matrix and fibers. It was also revealed that okra composites degraded less

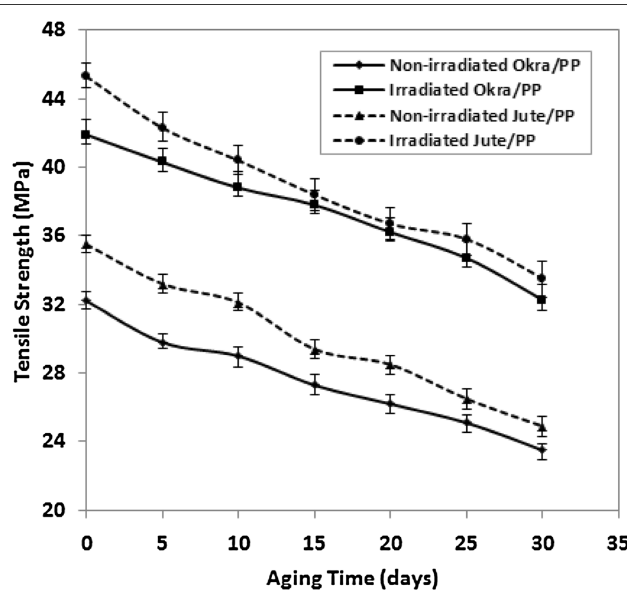

Fig. 10 Tensile strength of non-irradiated and irradiated (500 krad) composites against aging time (days)

than jute composites during thermal aging due to higher T_g value of okra than jute fiber (De Rosa et al. 2010). The degradation of fiber-reinforced composites is associated to the thermal depolymerization of hemicellulose, pectin and the cleavage of glycosidic linkages of cellulose firstly; the second corresponds to the degradation of α-cellulose present in the fiber (Albano et al. 1999; Monteiro et al. 2012).

Soil degradation study

The discontinuous fiber composites were subjected to soil degradation at ambient condition for up to 20 weeks. The TS values were evaluated and the results are given in Fig. 11. It was clear from figure that for both types of composites, the TS value decreased phenomenally with time. After 6 weeks of degradation, okra and jute composites lost almost 13 and 17% of TS, respectively. After 5 months of degradation, both the composites showed a significant loss of strength. Okra composites lost 21% strength and jute composites lost 26% strength, respectively. Both okra and jute are natural biodegradable and lignocellulose fiber. Cellulose has strong tendency to degrade when buried in soil (Khan et al. 2001). During soil degradation tests, water penetrates from the cutting edges of the composites and degradation of cellulose occurred and as a result, the mechanical properties of the composites decreased significantly. On the other hand, gamma (500 krad) irradiated composites exhibited better resistant to soil degradation due to the formation of cross-link. After 5 months of soil degradation, the irradiated okra composites lost 16% strength and jute composites lost 21% strength, respectively, it is because the gamma radiation might have initiated a kind of grafting process of the polymer chain of the cellulose, so less chance of water molecule to penetrate into the fiber. Hydrophilic nature of jute is more than okra, so jute composites showed less resistance to soil medium than okra composites.

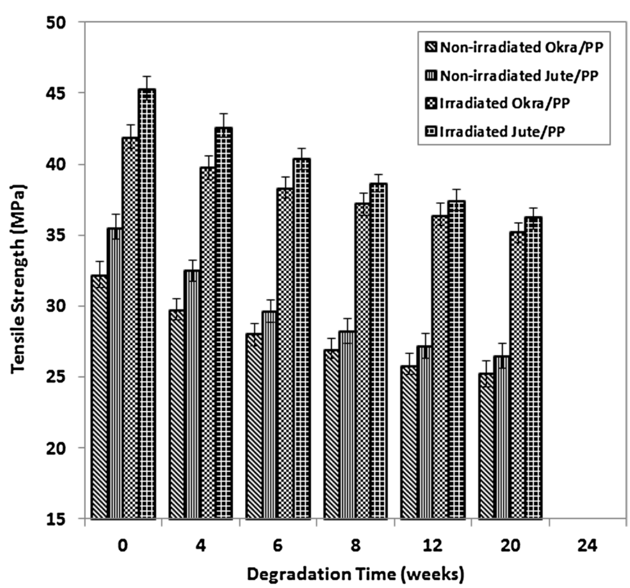

Fig. 11 Degradation of tensile strength of non-irradiated and irradiated (500 krad) composites under soil medium

Morphological study of the composites

SEM micrographs were used to understand the interfacial bonding of the composites. Figure 12a, b for Okra/PP and Fig. 12c, d show the tensile fracture surface of Jute/PP composites.

The figures specified that the fiber partly adhered to the binder material, demonstrating the weak interfacial bonding between fiber and matrix. It is detected that the fiber diameters are different, the fiber surface is harsh and small amount of fibers and particles adhered. From the images, agglomeration of fibers, the debonding of the PP and the cellulosic fiber is also found. Cellulosic fibers have –OH group in their structure, this type of bonding tends to render these materials more hydrophilic and subsequently more susceptible to moisture, interfering in the fiber-matrix interfacial adhesion. These recommend that the bonding between matrix and reinforcing fiber can be developed further. The physico-mechanical behaviors of composites significantly depend on the interfacial bond strength between reinforcement and matrix. Therefore, it is reflected that the tensile, bending and impact behaviors of the composite material can be further optimized by the use of appropriate coupling agents.

Conclusion

Okra fiber/PP and Jute fiber/PP-based composites (40% fiber by weight) were prepared successfully using compression molding and physico-mechanical properties were evaluated. It was examined that okra composites showed comparatively lower tensile, bending

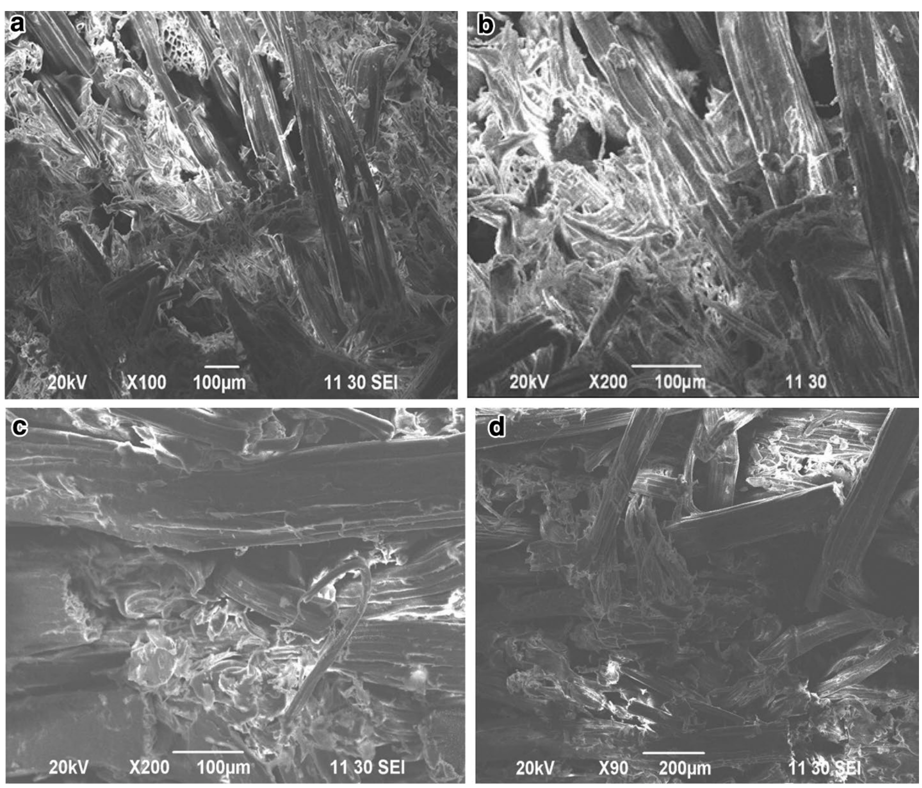

Fig. 12 SEM micrographs of Okra/PP composite (**a**, **b**) and Jute/PP composite (**c**, **d**)

and impact strength but better water resistant properties than jute composite. Okra/PP also exhibited reduced degradation properties in soil and heat medium than jute composites. Gamma radiation was applied on composites with the dose variation from 250–1000 krad at a dose rate of 330 krad/h. Investigation showed that at 500 krad dose composites performed the best mechanical properties than non-irradiated composites. The water uptake, soil and thermal degradation behaviors of non-irradiated composites were improved when composites were irradiated. Finally, it had been observed that gamma radiation is one of the powerful sources to enhance the physico-mechanical properties of Okra/PP and Jute/PP composites. SEM analysis showed that reinforcing fiber and PP matrix was in good adhesion, but also revealed that the interfacial interaction between the fiber and polymer could further be improved by using appropriate coupling agent. From this study, it can be concluded that okra can be used individually or by blending with jute fiber as potential reinforcement in the composite material for diversified applications.

Authors' contributions

SA designed the research work and ANMMR carried out the experiments as well as drafted the manuscript. RAK contributed to the data analysis of all test results. JH helped to prepare the manuscript. All authors read and approved the final manuscript.

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Acknowledgements

The authors whole-heartedly acknowledge Dr. Mubarak Ahmad Khan (Director General, Bangladesh Atomic Energy Commission) for giving the opportunity to perform the research work in Polymer Composite Laboratory, Institute of Radiation and Polymer Technology, Bangladesh Atomic Energy Commission, Dhaka. The authors also express thank Md. Saifur Rahman (Scientific officer, IRPT, Bangladesh Atomic Energy Commission) for his technical support and co-operation.

Competing interests

The authors declare that they have no competing interests.

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Received: 29 November 2017 Accepted: 8 May 2018
Published online: 26 November 2018

References

Alam, M. S., & Khan, G. A. (2007). Chemical analysis of okra bast fiber (*Abelmoschus esculentus*) and its physico-chemical properties. *Journal of Textile and Apparel Technology and Management, 5*(4), 1–9.

Albano, C., Gonzalez, J., Ichazo, M., & Kaiser, D. (1999). Thermal stability of blends of polyolefins and sisal fiber. *Polymer Degradation and Stability, 66*(2), 179–190.

Ali, K. I., Khan, M., & Ali, M. A. (1997). Study on jute material with urethane acrylate by UV curing. *Radiation Physics and Chemistry, 49*(3), 383–388.

Ayre, B. G., Stevens, K., Chapman, K. D., Webber, C. L., Dagnon, K. L., & D'Souza, N. A. (2009). Viscoelastic properties of kenaf bast fiber in relation to stem age. *Textile Research Journal, 79*(11), 973–980.

Blouin, F. A., & Arthur, J. C. (1958). The effects of gamma radiation on cotton part I: Some of the properties of purified cotton irradiated in oxygen and nitrogen atmospheres. *Textile Research Journal, 28*(3), 198–204.

Bullions, T., Gillespie, R., Price-O'Brien, J., & Loos, A. (2004). The effect of maleic anhydride modified polypropylene on the mechanical properties of feather fiber, kraft pulp, polypropylene composites. *Journal of Applied Polymer Science, 92*(6), 3771–3783.

Cantero, G., Arbelaiz, A., Llano-Ponte, R., & Mondragon, I. (2003). Effects of fibre treatment on wettability and mechanical behaviour of flax/polypropylene composites. *Composites Science and Technology, 63*(9), 1247–1254.

Czvikovszky, T. (1995). Reactive recycling of multiphase polymer systems through electron beam. *Nuclear instruments and methods in physics research section B: Beam Interactions with Materials and Atoms, 105*(1–4), 233–237.

Davenas, J., Stevenson, I., Celette, N., Cambon, S., Gardette, J., Rivaton, A., et al. (2002). Stability of polymers under ionising radiation: The many faces of radiation interactions with polymers. *Nuclear instruments and methods in physics research section B: Beam Interactions with Materials and Atoms, 191*(1), 653–661.
De Rosa, I. M., Kenny, J. M., Puglia, D., Santulli, C., & Sarasini, F. (2010). Morphological, thermal and mechanical characterization of okra (*Abelmoschus esculentus*) fibres as potential reinforcement in polymer composites. *Composites Science and Technology, 70*(1), 116–122.
Fortunati, E., Puglia, D., Monti, M., Santulli, C., Maniruzzaman, M., Foresti, M., et al. (2013a). Okra (*Abelmoschus esculentus*) fibre based PLA composites: Mechanical behaviour and biodegradation. *Journal of Polymers and the Environment, 21*(3), 726–737.
Fortunati, E., Puglia, D., Monti, M., Santulli, C., Maniruzzaman, M., & Kenny, J. M. (2013b). Cellulose nanocrystals extracted from okra fibers in PVA nanocomposites. *Journal of Applied Polymer Science, 128*(5), 3220–3230.
Gögus, F., & Maskan, M. (1999). Water adsorption and drying characteristics of okra *Hibiscus esculentus* L. *Drying Technology, 17*(4–5), 883–894.
Gowda, T. M., Naidu, A., & Chhaya, R. (1999). Some mechanical properties of untreated jute fabric-reinforced polyester composites. *Composites Part A: Applied Science and Manufacturing, 30*(3), 277–284.
Hassan, M. M., El-Hag Ali, A., Mahoud, G. A., & Hegazy, E. S. A. (2005a). Synergistic effect of short reinforced fibers and gamma rays on the thermal and mechanical properties of waste poly (propylene) composites. *Journal of Applied Polymer Science, 96*(5), 1741–1747.
Hassan, M. M., Islam, M. R., & Khan, M. A. (2005b). Surface modification of cellulose by radiation pretreatments with organo-silicone monomer. *Polymer-Plastics Technology and Engineering, 44*(5), 833–846.
Haydaruzzaman, Khan, A., Hossain, M., Khan, M. A., Khan, R. A., & Hakim, M. (2010). Effect of ultraviolet radiation on the mechanical and dielectric properties of Hessian cloth/PP composites with starch. *Polymer-Plastics Technology and Engineering, 49*(8), 757–765.
Islam, T., Khan, R. A., Khan, M. A., Rahman, M. A., Fernandez-Lahore, M., Huque, Q., et al. (2009). Physico-mechanical and degradation properties of gamma-irradiated biocomposites of jute fabric-reinforced poly (caprolactone). *Polymer-Plastics Technology and Engineering, 48*(11), 1198–1205.
Jawaid, M., Khalil, H. A., Bakar, A. A., & Khanam, P. N. (2011). Chemical resistance, void content and tensile properties of oil palm/jute fibre reinforced polymer hybrid composites. *Materials and Design, 32*(2), 1014–1019.
John, K., & Naidu, S. V. (2004). Sisal fiber/glass fiber hybrid composites: The impact and compressive properties. *Journal of Reinforced Plastics and Composites, 23*(12), 1253–1258.
Joseph, P., Joseph, K., & Thomas, S. (2002). Short sisal fiber reinforced polypropylene composites: The role of interface modification on ultimate properties. *Composite Interfaces, 9*(2), 171–205.
Karina, M., Onggo, H., Abdullah, A. D., & Syampurwadi, A. (2008). Effect of oil palm empty fruit bunch fiber on the physical and mechanical properties of fiber glass reinforced polyester resin. *Journal of Biological Sciences, 8*(1), 101–106.
Khalil, H. A., Hanida, S., Kang, C., & Fuaad, N. N. (2007). Agro-hybrid composite: The effects on mechanical and physical properties of oil palm fiber (EFB)/glass hybrid reinforced polyester composites. *Journal of Reinforced Plastics and Composites, 26*(2), 203–218.
Khan, M., Hinrichsen, G., & Drzal, L. (2001a). Influence of novel coupling agents on mechanical properties of jute reinforced polypropylene composite. *Journal of Materials Science Letters, 20*(18), 1711–1713.
Khan, M. A., Idriss Ali, K., Hinrichsen, G., Kopp, C., & Kropke, S. (1999). Study on physical and mechanical properties of biopol-jute composite. *Polymer-Plastics Technology and Engineering, 38*(1), 99–112.
Khan, M. A., Khan, R. A., Haydaruzzaman, Ghoshal, S., Siddiky, M., & Saha, M. (2009a). Study on the physico-mechanical properties of starch-treated jute yarn-reinforced polypropylene composites: Effect of gamma radiation. *Polymer-Plastics Technology and Engineering, 48*(5), 542–548.
Khan, M. A., Khan, R. A., Haydaruzzaman, Hossain, A., & Khan, A. H. (2009b). Effect of gamma radiation on the physico-mechanical and electrical properties of jute fiber-reinforced polypropylene composites. *Journal of Reinforced Plastics and Composites, 28*(13), 1651–1660.
Khan, M., Kopp, C., & Hinrichsen, G. (2001b). Effect of vinyl and silicon monomers on mechanical and degradation properties of bio-degradable jute-Biopol® composite. *Journal of Reinforced Plastics and Composites, 20*(16), 1414–1429.
Khan, G. A., Shaheruzzaman, M., Rahman, M., Razzaque, S. A., Islam, M. S., & Alam, M. S. (2009c). Surface modification of okra bast fiber and its physico-chemical characteristics. *Fibers and polymers, 10*(1), 65–70.
Li, J.-Q., Huang, Y.-D., Fu, S.-Y., Yang, L.-H., Qu, H.-T., & Wu, G.-S. (2010). Study on the surface performance of carbon fibres irradiated by γ-ray under different irradiation dose. *Applied Surface Science, 256*(7), 2000–2004.
Li, J., Huang, Y., Xu, Z., & Wang, Z. (2005). High-energy radiation technique treat on the surface of carbon fiber. *Materials Chemistry and Physics, 94*(2), 315–321.
Matthews, P. (1992). *Advanced Chemistry* (1st ed., pp. 152–156). UK: Cambridge University Press.
Miah, M., Ahmed, F., Hossain, A., Khan, A., & Khan, M. A. (2005). Study on mechanical and dielectric properties of jute fiber reinforced low-density polyethylene (LDPE) composites. *Polymer-Plastics Technology and Engineering, 44*(8–9), 1443–1456.
Mishra, S., Mohanty, A. K., Drzal, L. T., Misra, M., & Hinrichsen, G. (2004). A review on pineapple leaf fibers, sisal fibers and their biocomposites. *Macromolecular Materials and Engineering, 289*(11), 955–974.
Mishra, A., & Pal, S. (2007). Polyacrylonitrile-grafted Okra mucilage: A renewable reservoir to polymeric materials. *Carbohydrate Polymers, 68*(1), 95–100.
Mohanty, A., Khan, M. A., & Hinrichsen, G. (2000a). Surface modification of jute and its influence on performance of biodegradable jute-fabric/Biopol composites. *Composites Science and Technology, 60*(7), 1115–1124.
Mohanty, A., Misra, M., & Hinrichsen, G. (2000b). Biofibres, biodegradable polymers and biocomposites: An overview. *Macromolecular Materials and Engineering, 276*(1), 1–24.
Monteiro, S. N., Calado, V., Rodriguez, R. J., & Margem, F. M. (2012). Thermogravimetric stability of polymer composites reinforced with less common lignocellulosic fibers—an overview. *Journal of Materials Research and Technology, 1*(2), 117–126.

Onyedum, O., Aduloju, S. C., Sheidu, S. O., Metu, C. S., & Owolabi, O. B. (2015). Comparative mechanical analysis of okra fiber and banana fiber composite used in manufacturing automotive car bumpers. *American Journal of Engineering, Technology and Society, 2*(6), 193–199.
Rahman, M. R., Huque, M. M., Islam, M. N., & Hasan, M. (2008). Improvement of physico-mechanical properties of jute fiber reinforced polypropylene composites by post-treatment. *Composites Part A Applied Science and Manufacturing, 39*(11), 1739–1747.
Rajulu, A. V., & Devi, R. R. (2007). Tensile properties of ridge gourd/phenolic composites and glass/ridge gourd/phenolic hybrid composites. *Journal of Reinforced Plastics and Composites, 26*(6), 629–638.
Saba, N., Paridah, M., & Jawaid, M. (2015). Mechanical properties of kenaf fibre reinforced polymer composite: A review. *Construction and Building Materials, 76,* 87–96.
Sathishkumar, T., Navaneethakrishnan, P., Shankar, S., Rajasekar, R., & Rajini, N. (2013). Characterization of natural fiber and composites—a review. *Journal of Reinforced Plastics and Composites, 32*(19), 1457–1476.
Sawpan, M. A., Khan, M. A., & Abedin, M. (2003). Surface modification of jute yarn by photografting of low-glass transition temperature monomers. *Journal of Applied Polymer Science, 87*(6), 993–1000.
Srinivasababu, N., Rao, K. M. M., & Kumar, J. S. (2009). Experimental determination of tensile properties of okra, sisal and banana fiber reinforced polyester composites. *Indian Journal of Science and Technology, 2*(7), 35–38.
Startsev, O., Krotov, A., & Golub, P. (1999). Effect of climatic and radiation ageing on properties of VPS-7 glass fibre reinforced epoxy composite. *Polymer Degradation and Stability, 63*(3), 353–358.
Wan, Y., Wang, Y., Huang, Y., Luo, H., Chen, G., & Yuan, C. (2005). Effect of surface treatment of carbon fibers with gamma-ray radiation on mechanical performance of their composites. *Journal of Materials Science, 40*(13), 3355–3359.
Zaman, H. U., Khan, A., Hossain, M., Khan, M. A., & Khan, R. A. (2009). Mechanical and electrical properties of jute fabrics reinforced polyethylene/polypropylene composites: Role of gamma radiation. *Polymer-Plastics Technology and Engineering, 48*(7), 760–766.
Zaman, H. U., Khan, M. A., & Khan, R. A. (2012). Comparative experimental measurements of jute fiber/polypropylene and coir fiber/polypropylene composites as ionizing radiation. *Polymer Composites, 33*(7), 1077–1084.
Zaman, H. U., Khan, R. A., Khan, M. A., & Beg, M. D. H. (2013). Physico-mechanical and degradation properties of biodegradable photografted coir fiber with acrylic monomers. *Polymer Bulletin, 70*(8), 2277–2290.
Zaman, H. U., Khan, M. A., Khan, R. A., Mollah, M., Pervin, S., & Al-Mamun, M. (2010). A comparative study between gamma and UV radiation of jute fabrics/polypropylene composites: Effect of starch. *Journal of Reinforced Plastics and Composites, 29*(13), 1930–1939.