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Fabrication and Characterization of Jute Fibre Reinforced Polymer-based Decorative Composites: Effect of Gamma Radiation

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Abstract

The jute fibre (JF) reinforced polyethylene (PE), polypropylene (PP), and epoxy resin (ER) matrix composites were developed. The JF content was maintained to 30% by weight. Then tensile properties and impact strength were measured. The finest tensile properties were found for JF/PP composites. The tensile strength (TS), tensile modulus (TM), elongation at break (Eb%), and impact strength (IS) of the JF/PP composites were found to be 38.00 MPa, 1800 MPa, 12%, and 8.20 kJ/m^2 respectively. The bonds between JF and polymers of the developed composites were investigated and found good adhesion. The composite samples were exposed to gamma ray and it was found that gamma radiation have the potential to improve the tensile and impact strength of the JF-based polymer composites. The JF content polymer-based decorative composites were also developed. The outcomes of this investigation showed a minor decrease of the tensile and impact strength of the composites but enhanced the beauty of the composites noticeably. The developed JF/polymer composites have sufficient mechanical strength for many applications. pretty

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Introduction

The composite materials are comprised of fibre as reinforcement and polymer as the matrix. The fibre containing polymer-based composite materials are comprehensively used in many fields since their fantastic thermal and mechanical properties. Currently, composite materials gained much attention in the fields of packaging, construction, automobile, aeronautic, naval and biomedical applications. Synthetic fibre reinforced thermoset and thermoplastic composites earned a significant attention to the scientists in the last century. The composites are substituting conventional structural materials. There are several special advantages of the composites, such as good stiffness, nice mechanical strength, easy processing, and excellent resistance to the environment. A major number of polymers such as PE, PP, ER, polyvinyl chloride (PVC), polyester resin (PR) and fibres both natural or synthetic types are being used for the fabrication of the composites. Synthetic fibres such as glass, carbon, or aramid are used as the reinforcing agent for many composites. Recently, natural fibres such as cotton, hemp, jute, sisal etc. are using for the fabrication of bio-composites because of the environment friendly character of the natural fibres (Saber and Abdelnaby 2022; Jawaid *et al.*, 2019; Mohanty *et al.*, 2000, Maisha *et al.*, 2022, Senthilkumar *et al.*, 2018).

The JF is a biodegradable fiber that is very useful, relatively cheap and available. The main composition of JF is 82–85% holocellulose. However, JF has

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some drawbacks, such as strong absorption of moisture, low thermal resistance and varying thermo-mechanical properties (Gurunathan *et. al.*, 2015; Saheb and Jog 1999; Anindita *et. al.*, 2022). Natural fibres are undertaking an advanced revolution and as a result these fibres-based composites have the potential to substitute non-degradable synthetic polymeric composites. For example, boat hulls, automotive body parts, bath tubs etc. are partially or fully made of natural fibre-based composites. Natural fibres have many advantages such as relatively cheap, available, and biodegradable. The excellent thermo-mechanical properties with the biodegradable nature is very significant for the preference of natural fibre reinforced polymer composites in civil, automotive, aeronautic and others. At present, few automobile companies targeted to make partly for fully some of the components using biodegradable polymeric materials. It is reported that the door panels of a German car have been made from flax fibres-based composites. As a result, natural fibres have earned much curiosity among the scientists for applications in civil, automobile, aeronautic and biomedical areas (Ashik *et. al.*, 2015; Nam *et. al.*, 2014; Nguong *et. al.*, 2013; Paulo *et. al.*, 2018; Ali 2015; Kamrun *et. al.*, 2019).

In this investigation, gamma radiation is used. Gamma radiation is electromagnetic type radiation. Gamma radiation have a wavelength range below 100 picometer. Gamma radiation is the utmost energetic form of electromagnetic radiation and the energy level is greater than 100 keV. Gamma rays are emitted from an excited nucleus. The electromagnetic radiation is consists of photons. The photons of gamma radiation have the highest energy with the shortest wavelength. Gamma rays are emitted from Cobalt-60 (Co-60) and Caesium-137 (Cs-137). The isotope Co-60 is the most preferable for the gamma irradiators. Gamma rays have 1.17 MeV and 1.33 MeV energy levels that are released by Co-60. The application of gamma radiation has increased significantly in the recent years. There has been an uninterrupted growth in the expansion and application of gamma radiation technology in the last few decades. This technology is primarily using in polymer, coating, adhesive, and sterilization industries. Gamma irradiation technology is continuously increasing in many fields and developing new products. Therefore, this technology can be used in polymer composite industries also. The application of gamma radiation technology has some advantages. For example, this technology is a continuous process, need minimum time, less atmospheric pollution, curing at room temperature etc. (Shahirin *et. al.*, 2021; Steele 2001; Lung *et. al.*, 2015; Hallman *et. al.*, 2017; Pryke *et. al.*, 1995; Farhana *et. al.*, 2023).

The aim of this research was to develop JF reinforced PE, PP, and ER-based composites. The tensile properties of the developed composites were measured. The interfacial properties of the composites were also investigated. Composite samples were irradiated to find the efficacy of gamma radiation,. The decorative JF reinforced composites were intended to prepare for the decorative applications. It was expected that the fabricated JF incorporated composites will be partially degradable, decorative and have good mechanical properties.

Materials and Methods

Materials

Bleached JF (also called as hessian cloth) were purchased from Savar, Dhaka, Bangladesh. The granules of PE and PP were purchased from the Cosmoplene Polyolefin Company Limited, Singapore. The dyeing agent used in this investigation was from BD Lacquer Spray, China. Three dyes (yellow, green, red) were used to convert the JF to decorative JF. A digital image of PP granules and JF is shown in Figure 1. Epoxy resin was purchased from Shandong Deyuan Epoxy Resin Company Limited, China. In this research, JF is used as the reinforcing agent. The PE and PP are thermo-plastic type and epoxy resin is thermo-set type polymer. The chemical structure of the above four materials are shown in Figure 2.

Figure 1. Digital images of polypropylene granules (A) and JF (B).

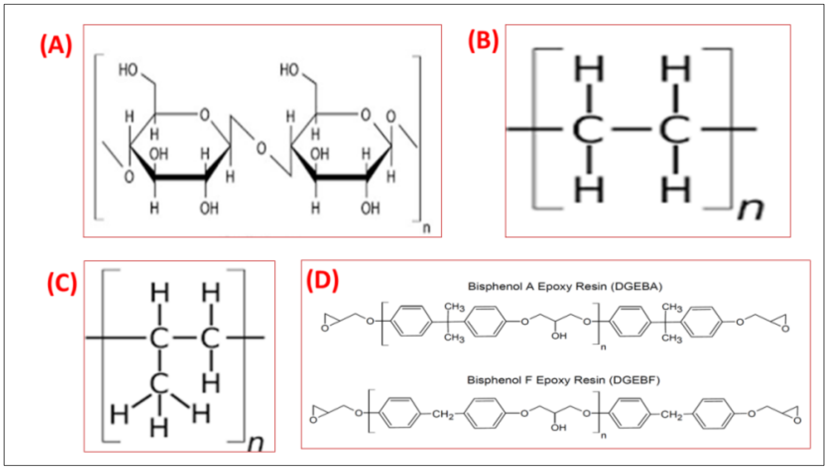

Figure 2. Structure of cellulose (A), polyethylene (B), polypropylene (C), and epoxy resin (D).

Methods

(i) Fabrication of the JF-based Composites: The granules PE and PP were used to fabricate polymer sheet. For making one polymer sheet, 10 gm of polymer granules were used. At first, polymer granules were placed between two steel plates. Then the sandwich construction was pressed in the heat press (Carver-3856, USA). The press was operated above the melting temperature of the polymer (120°C for PE and 180°C for PP). The steel plates were then cooled in another cold press machine. The resulting polymer sheet was then cut into the desired size for composite fabrication. The composites were prepared by using three layers of JF between four sheets of polymer. The composites were made by heat pressed the sandwich construction inside the press machine that was operated above the melting point of the polymers. The composite contains 30% JF. For the production of the decorative composites, JF samples were converted to decorative by using three dyeing agents. After that the decorative composites were fabricated using the same technique as mentioned above. The JF/ER composites were prepared by conventional method (Anindita *et. al.*, 2022; Akter *et. al.*, 2012).

(ii) Tensile and Impact Properties: Universal testing machine (Hounsfield Series-S, UK) was used for measuring the tensile properties of the composites. The cross-head speed was 1 mm/s. Dimension of the test specimen was: 60mm×15mm×2mm (ISO-14125). The IS of the developed composites was measured by using the impact tester (MT-3016, USA). Five tests were carried out for each experiment. A digital image of the fabricated composites is shown in Figure 3.

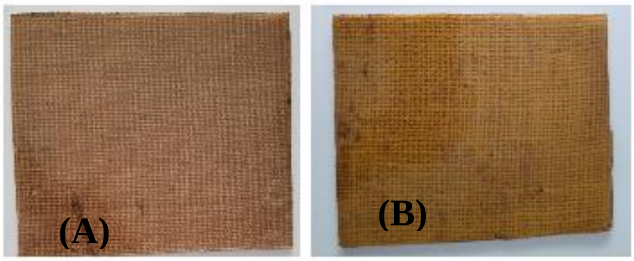

Figure 3. Digital pictures of JF/PP (A) and JF/ER (B) composites.

(iii) SEM Analysis: The bonds between JF and polymer were examined by SEM (Philips, UK) at the accelerating voltage 10 kV.

(iv) Gamma Irradiation: The JF/polymer composites were irradiated by Co-60 (350 kCi). The irradiation plant is situated at the Institute of Radiation and Polymer Technology (IRPT), Savar, Dhaka, Bangladesh. Figure 4 shows the gamma (Cherenkov) radiation.

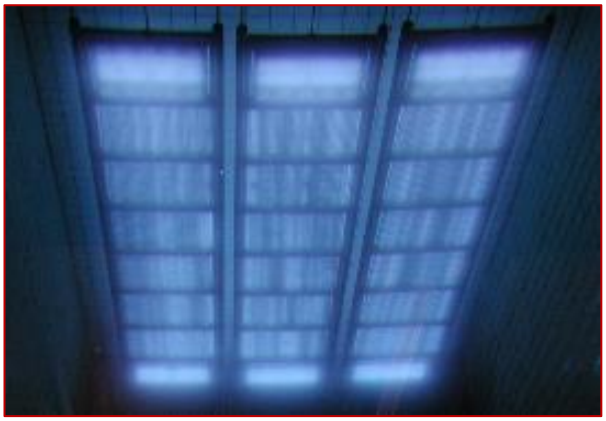

Figure 4. Emitting of Gamma Radiation.

Results and Discussion

(1) Tensile properties: The tensile properties of the JF and polymers were measured. Table 1 showed the tensile properties of JF, decorative JF, PE, PP and ER. The TS of JF was found to be 12 MPa and the decorative JF showed 10 MPa that indicated a slight decrease in strength. The TS of polymers (PE, PP and ER) showed very good strength for the composite fabrication. Similar results reported elsewhere (Khan *et. al.,* 2010; Miah *et. al.,* 2011).

Table 1. Tensile properties of JF, decorative JF, PE, PP and ER.

Sample Name	Tensile Strength (MPa)	Tensile Modulus (MPa)	Elongation at Break (Eb%)
JF	12	235	3.50
Decorative JF	10	215	3.80
PE	14	456	440
PP	22	530	378
ER	26	690	12

(2) Mechanical properties of the composites: The JF reinforced thermoplastic (PE and PP) and thermoset (ER) composites were fabricated then tensile and impact properties were evaluated. Table 2 showed the mechanical properties of the different types of composite materials. The TS of the JF reinforced PE, PP and ER composites were found to be 20.40 MPa, 38.00 MPa, and 32.00 MPa respectively. The IS of the JF reinforced PE, PP and ER composites showed 3.20 kJ/m^2, 8.20 kJ/m^2, and 4.45 kJ/m^2 respectively. The highest TS and IS values were observed for PP-based composites. The highest TM values were also found for PP-based composites. On the other hand, maximum values of Eb% were noticed for PE-based composites which is normal because the Eb% of PE is higher that PP and ER. The results presented here are supported by the published data (Khan *et. al.,* 2010; Miah *et. al.,* 2011; Gupta and Srivastava 2017).

Table 2. Mechanical properties of the composites.

Sample Name	Tensile Strength (MPa)	Tensile Modulus (MPa)	Elongation at Break (%)	Impact Strength (kJ/m^2)
PE/JF	20.40	800	16.00	3.20
PE/decorative JF	18.90	720	20.00	3.12
PP/JF	38.00	1800	12.00	8.20
PP/decoraitve JF	35.00	1680	14.00	6.50
ER/JF	32.00	1150	2.70	4.45
ER/decorative JF	29.00	1120	2.80	4.30

(3) Study of the fiber matrix bonds: The bonds between JF and polymer inside the composites were examined by SEM. Figure 5 showed the SEM image of the fracture sides of JF/PP (A) and JF/ER composites. For JF/PP composites, the interfacial bond between fiber and matrix is quite good. The polymer PP is covered the surfaces of the JF that is clearly visible in the images. In contrast, for JF/ER composites, fibers are not clearly visible. The JF is totally enclosed by polymers that indicated good mechanical bonds. For both types of the composites, the SEM images showed better fiber-matrix bond which is responsible to enhance the tensile strength.

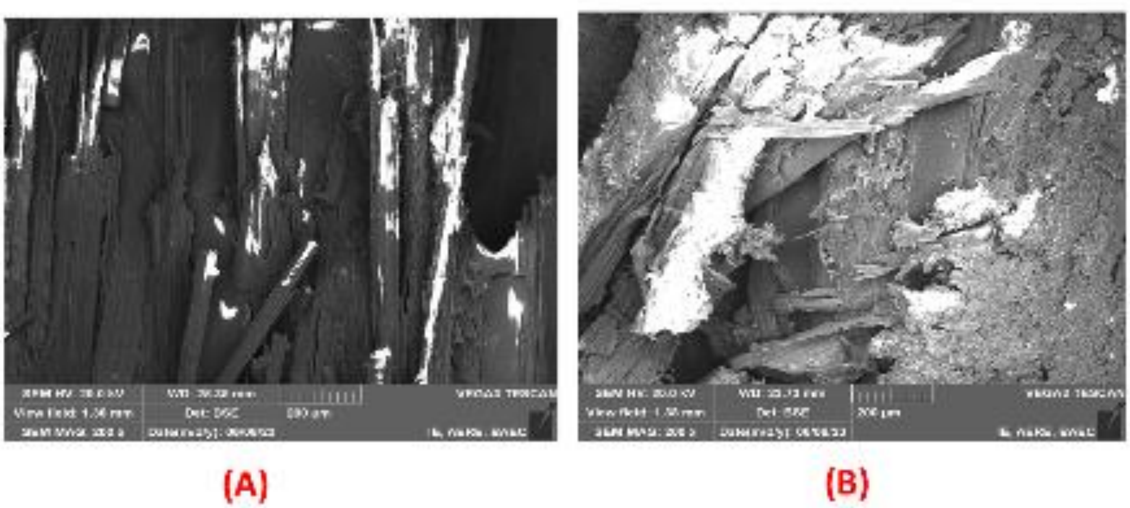

Figure 5. SEM image of JF/PP (A) and JF/ER (B) composites.

(4) Effect of gamma radiation: The developed JF/polymer composites were irradiated by Co-60 gamma source. The doses varied from 1, 5, 10, and 25 kGy. Both JF/PE and JF/PP composites gained strength at the dose of 5 kGy. On the other hand, JF/ER composites gained strength at 10 kGy dose. The results are presented in Table 3. The TS of JF/PE composites was found to be 20.40 MPa. When the composite samples were gamma irradiated at the doses of 1, 5, 10 and 25 kGy then the TS values reached to 22.00, 26.40, 25.20 and 18.30 MPa respectively. This is clear that at 5 kGy dose, the composite samples showed the highest strength. At higher gamma radiation dose, the

strength of the composite samples decreased significantly. It is reported that at low doses of gamma radiation the polymeric materials gained strength and at higher doses the strength decreases because at higher doses the bond inside polymer started to break. Radiation exposed JF-based composites may result in cross-linking and therefore yields higher tensile properties to a certain level of dose. Active sites inside the polymer might be produced by the exposure of gamma radiation. As a result good bnonding may happen between JF and polymer. This may be the reason for the increased mechanical properties of the JF-based polymeric mateials (Akter *et. al.*, 2012; Zaman *et. al.*, 2009).

(5) Tensile and impact properties of the decorative composites : In this investigation, three types of dyeing agents (yellow, green and red) were used to convert natural JF to decorative JF. The TS of the decorative JF reinforced PE, PP and ER-based composites were found to be 18.90 MPa, 35.00 MPa, and 29.00 MPa respectively. Results showed that the highest TS values were observed for JF/PP composites. Equally, the highest TM (1680 MPa), and IS (6.50 kJ/m^2) values were noticed for the JF/PP composites compared to PE and ER-based decorative composites. Figure 6 showed the photos of the JF-based decorative composites.

Table 3. Results of the irradiated polymer/JF composites.

Sample Name	Tensile Strength (MPa) of the Composites				
	Control	1 kGy	5 kGy	10 kGy	25 kGy
PE/JF	20.40	22.00	26.40	25.20	18.30
PE/decorated JF	18.90	20.10	23.00	21.40	15.45
PP/JF	38.00	40.15	43.20	40.15	31.30
PP/ decorated JF	35.00	37.00	39.30	36.20	28.20
ER/JF	32.00	33.00	38.00	33.00	23.20
ER/ decorated JF	29.00	26.00	32.00	26.00	20.30

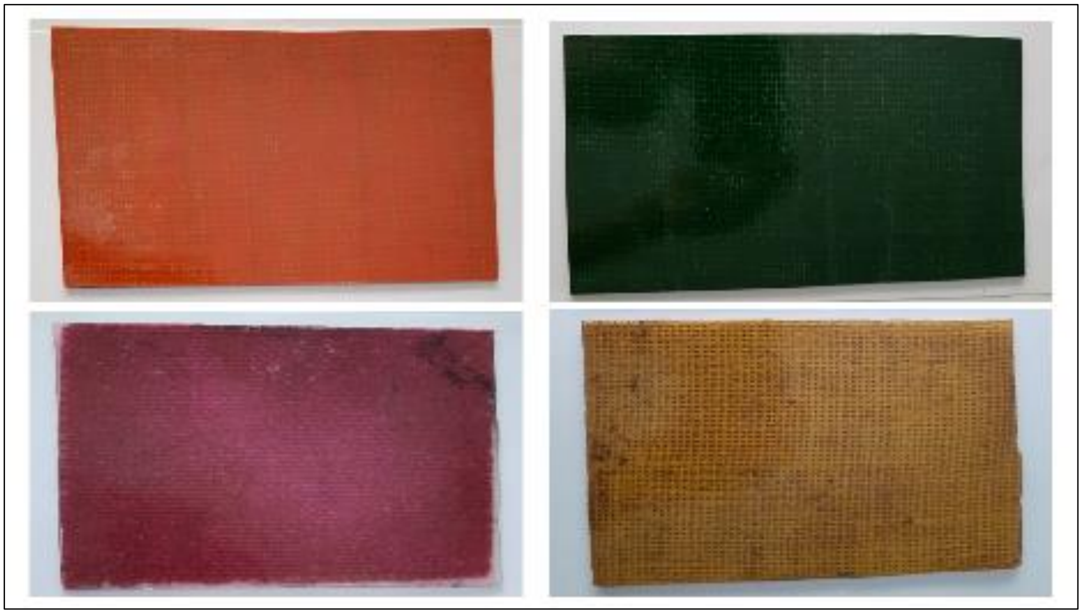

Figure 6. JF/PP-based decorative composites.

The developed decorative composites have slightly lower tensile strength compared to the control composites. Actually JF is intensely hydrophilic, as a result mechanical strength can decrease during processing of the composites. The mechanical properties of the fabricated decorative composites are in the worthy range for the diverse applications of the composites, especially for the decorative purposes. The appearance of all the decorative composites is very promising compared to control composites. Normal JF-based composites are not so suitable for decorative applications but decorative JF-based composites look very attractive. This investigation showed a new dimension of research for the scientists to use the JF/polymer composites for decorative applications.

Conclusion

The JF reinforced thermoplastic (PE and PP) and thermoset (ER) composites were fabricated successfully. The JF/PP composites showed the best mechanical performance over JF/PE and JF/ER composites. The bonds between JF and polymer inside the composites were quite good. Gamma radiation have the capacity to enhance the tensile strength of the JF-based composites. The composites became decorative by dyeing the JF. The decorated composites also showed good tensile strength and suitable for furniture and interior panel applications. The developed JF-based decorated composites appeared very attractive and can be the alternative of the synthetic polymeric materials. The decorative JF-based composites are partly biodegradable also. Finally, this investigation opened a door of interest for the scientists using JF for many applications.

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