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Jute/Polyester Composite Development: Radiation Effects Determination

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ABSTRACT

Jute fabrics served as reinforcements in the field of natural fiber-based composites. A 4-layer jute-polyester matrix composites are developed using a stacking sequence. The mechanical performance of the jute/polyester composites was evaluated as an improvement using γ-irradiation dosages of 2.5, 5 kGy, 7.5, and 10.0 kGy. After irradiation, the tensile properties of jute/polyester composites increased significantly, TS 15.77 %, BS 30.93 %, and IS 15 %. The Scanning Electron Microscopy (SEM) analysis showed good fiber-matrix adhesion, while Energy Dispersive Spectrum (EDS) exhibited carbon and oxygen. To sum up, 7.5 kGy is an effective dose for enhancing the properties of jute/polyester resin which will open a new research avenue for natural fiber-matrix composite development.

Keywords: Gamma irradiation, Jute fibers, Jute/polyester composites, Mechanical properties enhancement, Thermoset polymer matrix

INTRODUCTION

Natural fibers, particularly those derived from plants show promise as an environmentally friendly substitute for conventional materials [1-2]. Recently, natural fiber-reinforced polymer composites have gained huge popularity. Environmental issues have compelled scholars to concentrate on creating "green composites," which has led to increased usage of jute fiber as reinforcement [3]. Natural fibers have a few benefits over synthetic fibers, such as being less expensive, non-toxic, renewable, biodegradable, and having a similar specific strength and stiffness [4-5]. In various ancient industries, professionals such as architects, engineers, and business owners had been working to develop intricate applications for materials made of composites. The development of plastics has had a significant impact on contemporary composite materials. Contrarily, plastic cannot deliver great rigidity and strength for structural purposes. Plastics, therefore, need to be strengthened more for structural advances [6-7].

Humans had used functional constitutional materials like traditional wood, alloys, and reinforced concrete before discovering polymer-based composites. Combining polymers with synthetic fiber to produce a composite material advantageous for humans is a significant achievement. Nowadays, synthetic fiber-reinforced composites have attracted more attention [8-9]. However, scientists discovered flaws in these artificially reinforced composite materials and started looking for solutions. Such composites have a high density, are corrosive, have poor manufacturing, and are expensive [10-11]. Due to their sustainability, affordability, renewability, lightness, and biodegradability, fiber-based composite is regarded as the most innovative material. Having their superior performance, thermoset resins like polyester, unsaturated polyester resins (UPR), and epoxy resins are frequently cast off to make fused materials. Usually, the matrix phase of a

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composite is made of biopolymer, while the enhancement phase is made of cellulose fibers. Therefore, scientists are still investigating whether using natural fibers in composites rather than synthetic ones might be like [12–14].

Natural fiber has created a possibility to replace synthetic fiber-reinforced composite. However, they have some drawbacks like moisture absorption, weak compatibility with some matrices, and poor swelling properties, creating cracks and brittleness formation with matrix composites. To overcome the obstacles of the natural fibers, numerous modification techniques were introduced more likely chemical treatments to reduce water affinity and improve polymeric matrices adhesion [15-16]. Chemical modification is used more preferably to improve the physicomechanical properties. However, chemical treatments have a lot of adverse effects on the environment [17]. Ionizing radiation is a physical process of modifying synthetic and natural polymers taking parts such as polymerization, crosslinking, and degradation [18]. Thus, the aim is to develop a woven jute composite incorporated with a polyester resin matrix. The radiation effects on mechanical properties improvement of developing composite are to be determined which will open a research avenue in the composite fields.

MATERIALS AND METHODS

Material

Jute fabric was a brand of Bangladesh Jute Research Institute. Polyester resin as a matrix and methyl ethyl ketone peroxide as an initiator were collected in Singapore. The properties of jute fabrics and matrix are presented in Table 1.

Table 1: Characteristics of jute and unsaturated polyester resin [19] and woven jute fabric [20].

Important properties	Jute	Polyester resin
Moisture content (wt.%)	12.5–13.7	-
Water absorption (%) within 7 days	-	0.35
Heat distortion temperature (°C)	-	67.3
Impact strength (MPa)	-	38.5
Bending strength (MPa)	-	82.37
Bending Modulus (MPa)	-	5257
Tensile properties (MPa)	320–800	29.41
Tensile modulus (GPa)	8–78	-
Elongation at break (%)	1–1.8	3.2

METHODOLOGY

Fabrication of composite laminates

Jute fabric was dried at 100 °C for an hour. The jute-matrix as polyester resin ratio (1:2), and matrix-MEKP ratio (100:1) were stirred gently to prepare a solution, immediately applied to the reinforcements. The composites were impregnated using compression molding (Carver, INC, USA), maintaining a temperature (90 °C) for 10 min [19]. Jute fabrics were cut into the required dimensions, the composites were cured for 24 h at ambient temperature.

Composite Irradiation

A Co-60 γ-source was used to irradiate the composite laminates, exposed γ-dose was 0, 2.5, 5, 7.5 10.0 kGy.

Tensile Properties

Tensile strength was performed using a Universal Testing Machine (UTM) [21] by the American Society for Testing and Materials standard (ASTM, D3039). The crosshead speed was 5 mm/min, a gauge length of 50 mm, a flat sample with a dimension of 180 mm length and 15 mm width.

Bending Properties

Bending strength was performed using UTM, 5 mm/min crosshead speed, 50 mm gauge length [22], specimen size was 60 mm in length, and 15 mm in width.

Impact Properties

The impact strength was measured by a Universal Impact Tester, ASTM D256, Izod mode (Hung TA Instrument, Taiwan). The testing machine assembled a 2.63 kg hammer, 150° lift angle, and 30.68 mm gravity distance with a mass weight of 2.63 kg. The sample size was length of 55 mm, width of 12.7, notch depth of 2.54 mm with an angle of 45±1°, and a radius of curvature at the apex of 0.25±0.05 mm.

Scanning Electron Microscopy (SEM)

Test specimens' fracture surfaces were sputtered with Au using a sputter/coater before SEM examination, and Energy Dispersive Spectroscopy data was obtained. The fracture surfaces of the specimens were inspected using a Field Emission ultra-high resolution scanning electron microscope (FE-SEM ZEISS).

RESULTS AND DISCUSSION

Mechanical properties of radiation-induced composites

The radiation impacts of mechanical characteristics of jute/polyester composites reinforced with jute are depicted in Figure 1. Due to the application of radiation doses, the tensile properties were slightly increased up to the dose of 7.5 and then decreased. Tensile strength, bending strength, tensile modulus, bending modulus, and impact strength for jute/polyester composites were determined to be 104.2 MPa, 225.2 MPa, 6.83 GPa, 11.2 GPa, and 35.2 kJ/m^2 following a radiation dosage of 7.5 kGy [19], [23]. The tensile strength gradually increased up to the radiation dose of 7.5 kGy. This may be because crosslinking of HO- (hydroxyl group) of jute and the matrix group of polyester resins, creating a strong hydrogen bond. After 7.5 kGy dissociation occurred, the H bond broke and decreased in strength (Figure 1). However, the bending strength was increased for the dose of 5 kGy and remained stable for the dose of 7.5 kGy then drastically decreased. Figure 2 demonstrated that the tensile and bending modulus increased for the dose of 7.5 kGy and, then it was decreased. The impact strength also followed the same trend as the initial impact strength of 30.6 kJ/m^2 and the highest impact strength was 35.58 for the dose of 5 kGy.

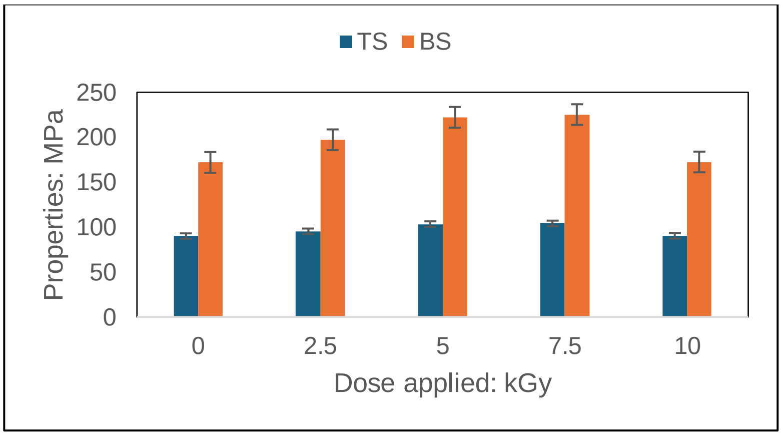

Fig 1: The Tensile Strength (TS) and Bending Strength (BS) of development composite, effects of radiation doses (0-10 kGy, O means without radiation).

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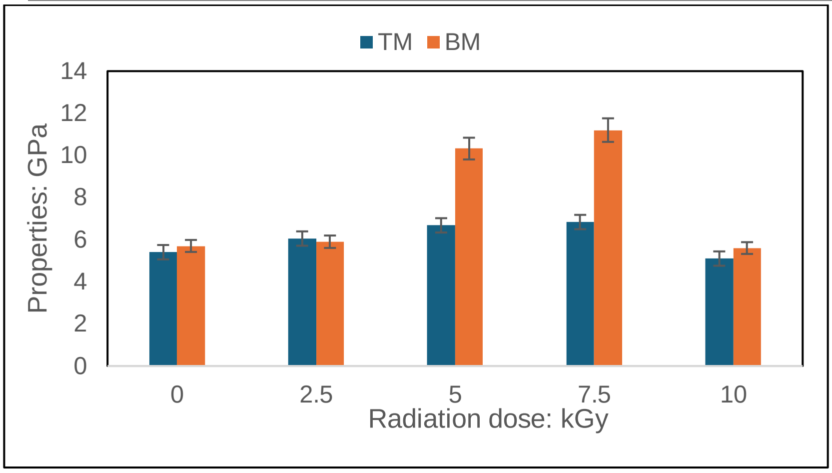

Fig 2: Tensile Modulus (TM) and Bending Modulus (BM) of developed composite, effects of radiation doses (0-10 kGy, 0 means control).

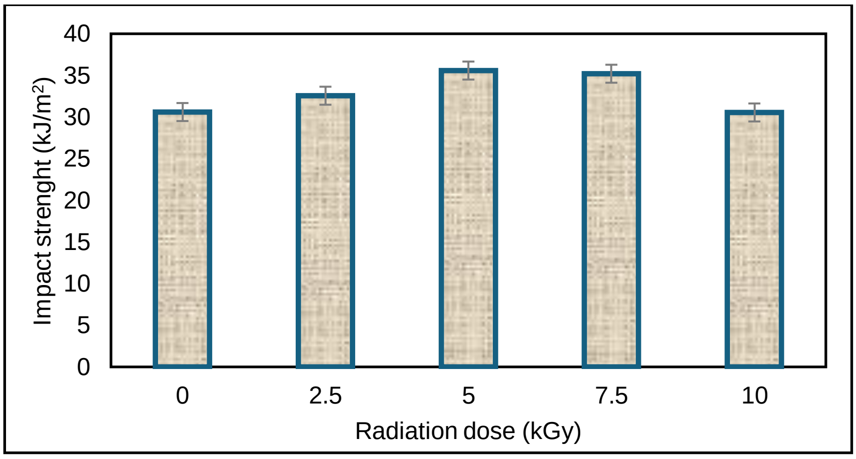

Fig 3. Effects of radiation on Impact Strength (IS) of the developed composite

Gamma-(γ) Radiation Effectiveness on Mechanical Properties

The data indicates an approximate rise of different properties as shown in Figure 4. In illustrating the effects of radiation on jute/polyester composite, results show a significant improvement in bending strength (28%) and tensile strength (14%). The modulus of tensile and bending followed the same magnitude (~20%) (Fig. 4). Finally, it is observed that 7.5 kGy is an effective dose for enhancing the mechanical properties over control samples of jute-polyester composite.

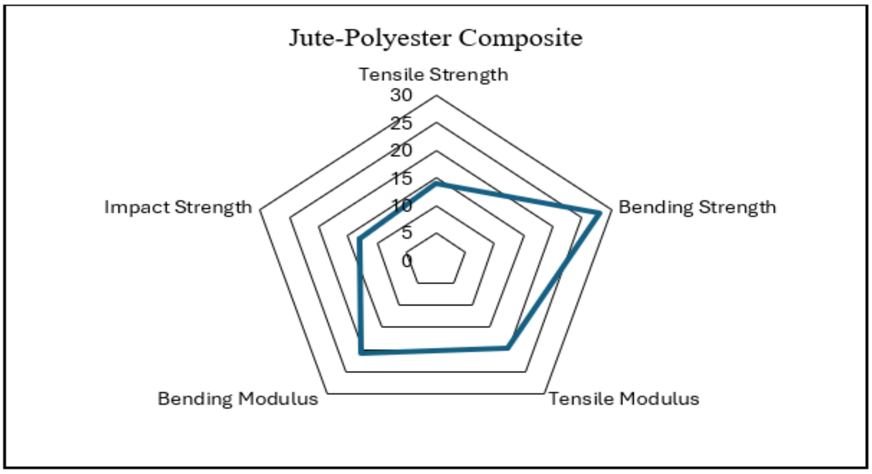

Fig 4: The Radiation dose (7.5 kGy) effectiveness of the composite on mechanical properties

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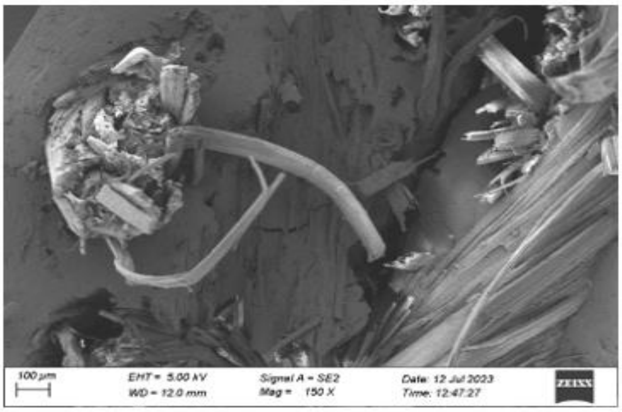
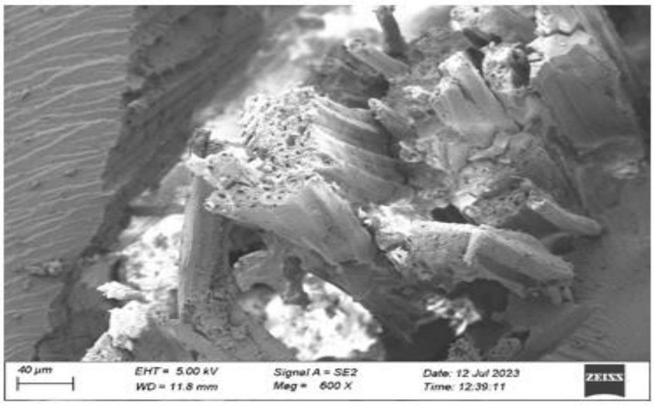
Scanning Electron Microscopy- Energy Dispersive Spectroscopy (SEM-EDS)

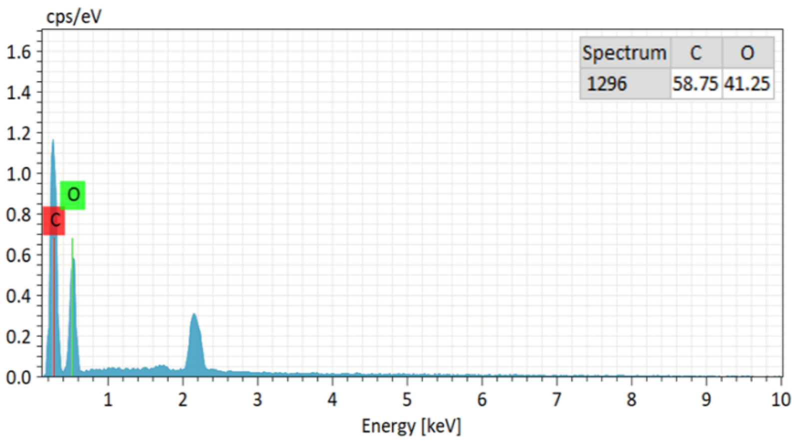
The SEM topography of the jute/polyester (a, b) composites is shown in Figure 5. Tensile test specimens with broken surfaces were used to capture the SEM pictures. These composites showed their typical failure patterns under tensile strain, but the fiber breakage pattern is distinct. Regarding jute/polyester composites, the jute fiber bundles' fracture tips exhibit rough and uneven surfaces (Fig. 5 a, b). A jute fiber cross-section that is hollow is shown in Figure 5a, suggesting the potentiality of the void (Fig. 5 b) [24-25]. Under tensile loading, jute fibers typically come out, non-brittle malfunctions and matrix cracking happens (Fig. 5 a, b) [8] In jute/polyester composites, the elemental data of the fibers derived from EDS analysis show that there are carbon (C) and oxygen (O) [26–28]. The jute/polyester composites exhibited the elements and weight % as carbon (58.75) and oxygen (41.25).



(a)



(b)



(c)

Fig. 5: SEM pictures of the jute/polyester composites' fracture surfaces (a–b); the elemental composition is shown in (c).

CONCLUSION

The mechanical properties are enhanced using radiation doses. Jute/polyester composites may create a strong interfacial bond between polyester matrix and jute fabrics. The properties such as tensile and bending strength, tensile and bending modulus, and impact strength improved by 14.1, 28, 19.70, 20.81, and 13% for the gamma radiation. Finally, 7.5 kGy dose is more effective for enhancing composites' properties.

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