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Comparative Experimental Studies on the Physico-mechanical Properties of Jute Caddies Reinforced Polyester and Polypropylene Composites

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Abstract Non-woven jute caddies (JC, jute wastage) reinforced unsaturated polyester resin (UPR) and polypropylene (PP)-based randomly oriented discontinuous fibre composites with fibre loading 40-65% were fabricated by compression molding. The influence of the addition of fibre loadings on the mechanical properties such as tensile strength (TS) and tensile modulus (TM), bending strength (BS) and bending modulus (BM) and impact strength (IS) of the composites was investigated. Based on the fiber loading, around 55% JC reinforced UPR composite yielded better mechanical properties compared to the JC/PP composite. To improve the compatibility between fibre and matrix, the composites were irradiated with gamma rays (Co-60) of dose varied from 2.5 kGy to 12.5 kGy. Tensile and flexural properties of the composites were found to be improved significantly after irradiation. TS and BS of JC/UPR composites increased 29.86 and 14.60% respectively at 7.5 kGy while for JC/PP composites the increments were 21.69 and 7.78% respectively at 5.0 kGy. Water uptake tests of untreated and irradiated composites were carried out in deionized water where, the water-resistance properties of both kinds of irradiated composites were found to improve almost equally. Degradation tests of the composites were performed in soil medium and it was observed that JC/UPR composites lost much of its original strength and modulus compared to that of the JC/PP composites.

Keywords: *Jute caddies, unsaturated polyester resin, polypropylene, irradiated composite, mechanical tests*

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1. Introduction

In modern world jute fibre plays a vital role in the country of median economy. This fibre of commerce is isolated from the stem of two cultivated species of jute, tossa jute (Corchorus olitorious L.) and white jute (C. capaularies L.) [1]. In Bangladesh the actual production of jute in the fiscal year 2012-2013 was 1.363 million tonnes [2]. Jute industries generate annually about 30,000 tonnes of processing waste as by-products, commonly known as jute caddies [3]. Jute caddies are generally created from two kinds of machine clean; one is Single Machine Clean and another one is Double Machine Clean. Both are come from Broad Looms. The major constituent of this waste is unspinnable short jute fibre. The other minor constituents are batching oil, machine oil and grease, barks of jute plant and inorganic components and dirts. Traditionally jute industry has been used this waste along with coal as fuel for the boiler to generate steam, which was required to run the sizing and calendaring machines. Use of caddies as a fuel is problematic, mainly due to its poor fuel value or thermal efficiency and low bulk density. Besides this, during the past decade, there has been significant changed in the products mix of the jute industry and sacking fabrics have emerged as the major product. Hessian and carpet backing fabrics, which are the major cause of steam consumption in a jute mill, are produced in a far less quantity than before, thereby lowering the requirement of steam by jute mills [4,5]. This waste also used for making insulation in coach roof, electric cable, all kind of sits cushion, car false panel etc. After meeting the demand of the country, it is now exported to the foreign countries. This potential waste can find its application in many ways such as, biogas production, nonwoven products, composites, biomass energy and handmade paper.

Jute caddies are mainly randomly oriented discontinuous fibres which are considered as quasi-isotropic on the macroscopic level [6]. Jute caddies based non-woven fabrics was found suitable as reinforcing material in making Fiber Reinforced Plastic (FRP), thereby replacing costlier glass fibre [7,8]. These FRPs were developed by reinforcing jute caddies based non-wovens in water-soluble thermosetting resin viz., urea formaldehyde while water soluble phenolic resin was used for making exterior grade board, which can well substitute plywood. Besides the cost advantage of these composites, the wear and tear of machinery is supposed to be lower when natural fibres like jute caddies are used in place of glass fibre. The reasons behind the use of jute caddies are its lower cost and availability. The lower specific gravity and higher specific modulus of jute plays a major role in these products applications. The products developed include corrugated sheet, cooling tower, fan blade, pipe, washbasin, serving tray, speaker box, automobile components, toolbox, traffic signal light case, chair, tabletop, country boat, etc.

Unsaturated polyester resin (UPR) is one of the most important matrices for polymer composite application. Unsaturated polyester is the macromolecules with a polyester backbone and belongs to category of the thermoset resin. This is the condensation product of unsaturated acids or anhydrides and diols with/without diacids. The unsaturation present in this type of polyesters provides a site for subsequent cross-linking. This resin is compounded with various fillers, reinforcements and cured by using free radical initiators to yield thermoset articles having a wide range of chemical and mechanical properties depending upon the choice of cross- linking agents, initiators and other additives. This versatility in the properties of the final thermoset product associated with comparatively low cost has increased the interest in this resin as an important matrix material for wide range of applications [9]. The UPR can be easily handled in processes like hand layup, filament winding, resin transfer molding in the liquid form. They can also be used in molding compounds, moreover, they possess good thermal, mechanical and service properties; hence, this resin is used in a number of applications like insulation coatings, fiber reinforced plastics (FRPs) products, sandwich panels, sheet molding compounds (SMC), bulk molding compounds (BMC etc.).

Matrix material is the most important part of a thermoplastic composite. Thermoplastic composite is manufactured using potentially high performance resin such as polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC) etc. Among them polypropylene (PP) was used as one of the matrix materials in the current study because it has some excellent qualities for composite fabrication. PP possesses several useful properties such as low density, good flex life, sterlizability, good surface hardness, scratch resistance, very good abrasion resistance transparency, dimensional stability, gas barrier properties, high impact strength, and so on. PP is also very suitable for different type composite processing like, filling, reinforcing, and blending. PP with fibrous natural polymers is one of the most promising routes to create natural-synthetic polymer composites [10,11,12,13].

The aim of the present studies was to fabricate and comparative study on the physico-mechanical properties of two types composites made of jute caddies reinforced polyester and jute caddies reinforced polypropylene.

2. Experimental

2.1. Materials

In this research work jute cadies (JC), unsaturated polyester resin (UPR), polypropylene (PP) methyl ethyl ketone peroxide (MEKP) and methanol were used as materials. JC was collected from "Janata Jute Mills Limited", Dhaka, Bangladesh. UPR was purchased from NORSODYNE, Malaysia. Polypropylene (PP) pellets were procured from Cosmoplene Ltd., Singapore. MEKP was purchased from MERCK, Germany. Methanol was purchased from MERCK, India.

2.2. Process of Composites Fabrication

2.2.1. JC/UPR Composite

The jute caddies (JC) was cleaned properly to remove pieces of barks, rots, jute sticks remnants and very short fibres. JC was dried for half an hour at 100° C in an oven to make it moister free. JC mat was prepared from jute caddies by pressing at 90°C for 5 minutes between two steel molds under 5 bar consolidation pressure in the heat press (Model 3856; Carver Inc., USA). A matrix solution was then made with UPR, MEKP and methanol. Methanol (99% conc.) was used in the solution to make it dilute and low viscous and the ratio of UPR and methanol was maintained always same in the solution. The JC mat was then cut with required size and was completely submerged in the pre-prepared matrix solution. The jute mat was then degassed with a roller for 2 minutes at room temperature to remove the entrapped air bubbles. After that the JC mat was cured under a pressure of about 5 metric ton at room temperature for 5 minutes with the presence of a 6 mm spacer to produce the composite on the same thickness for different fibre contents. The composite was then post-cured at 90°C for 15 minutes and finally it was allowed to cool naturally to room temperature for about 30 minutes. JC/UPR composite panels with different fibre weight percentage were prepared and the specimens of the required dimensions were cut and used for several testing and treatment.

2.2.2. JC/PP Composite

For making one PP sheet, granules of PP (about 10 g) were placed into two steel plates and placed into the hot press. At first the hot press was operated at 180°C for 5 minutes without pressure. Steel plates were then pressed at 5 bar consolidation pressure for 2 minutes. The plates were then cooled for 3 minutes in a separate press having a cooling system under 5 bar pressure at room temperature. The resulting PP sheet was cut into the desired size for composite fabrication. Composites were prepared by sandwiching two layers of fibres between three sheets of PP. Randomly oriented fibres were placed between the PP sheets. It was then placed again into two steel plates and heated at 180°C for 5 minutes to soften the polymer prior to pressing 5 bar pressure for 2 minutes. The fibre weight fraction of the composites was calculated. Thickness of the composites was maintained using shims. JC/PP composite panels with different fibre weight contents (wt%) were prepared and the specimens of the required dimensions were cut and used for testing.

2.3. Gamma Irradiation

The composite samples were irradiated using a Co-60 gamma source (25 kci) of the Bangladesh Atomic Energy Commission, Savar, Dhaka, for different doses (2. 5–12. 5 kGy) at the rate 6 kGy/h. In gamma radiation, model gamma beam 650 is loaded with source GBS-98 that comprises 36 double encapsulated capsules. Type C-252 loaded with Co-60 pellets was used.

2.4. Methods of Physico-mechanical Tests

Tensile, flexural and izod impact tests were conducted at 25°C. Composite samples were cut to the required dimension using a band saw. For each test and type of composite, five specimens were tested and the average value with standard deviation was reported.

2.4.1. Tensile Test

Tensile properties are the most important single indication of strength in a material. The force needed to pull the specimen apart is determined, along with how much the material stretches before it breaks. Tensile tests were conducted according to ASTM D 638-01 [14] using a Universal Test Machine (Hounsfield series, model: INSTRON 1011, UK). The dimensions of the test specimens were (ISO 14125): 60 mm × 15 mm × 2 mm. Specimens were placed in the grips of a Universal Test Machine at 50 mm grip separation and pulled with a cross-head speed of 10 mm/min until failure. Following equation was used to measure the tensile strength of the composites.

$$\text{Tensile Strength, } TS = \frac{M}{t \times w} \quad (1)$$

Where, M is the maximum applied load (kN) by the machine, t is the thickness (mm) and w is the width (mm) of the specimen.

2.4.2. Flexural Test

Flexural testing is used to determine the flex or bending properties of a material. Specimens of 150 mm length and 15 mm width were cut and placed between two points or supports of the apparatus and initiating a load using a third point or centre. In the present study the recommended span to depth ratio was 16:1 as shown in Figure 1 below. The specimens were tested at a crosshead speed of 2 mm/min. The test was conducted on the same machine used for tensile testing. The flexural or bending strength was found out by using following equation.

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

Where P is the maximum load; L is the distance between the supports (mm); b is the width of the specimen (mm) and d is the thickness (mm).

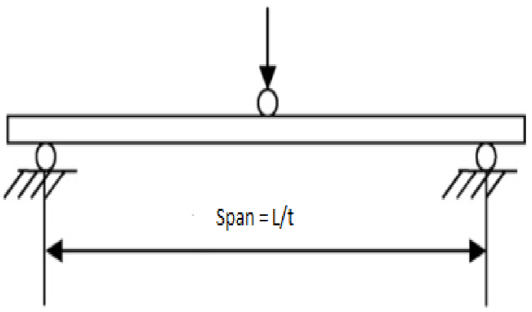

Figure 1. Flexural test configuration

2.4.3. Izod Impact Test

Izod Impact is a single point test method that measures a materials resistance to impact from a swinging pendulum. Izod specimens are generally notched to prevent deformation of the specimen upon impact. In the present study impact strength of composites was conducted on notched mood according to ASTM standard D-256 using a Universal Impact Tester (Hung Ta Instrument Co. Ltd. Taiwan), model-HT-8041B IZOD. The nominal energy of the pendulum was 150 kg-cm, lifting angle (α) was 150°, force torque (WR) was 80. 811 kg-cm. First of all, the specimen was clamped into the pendulum impact test fixture with the notched side facing the striking edge of the pendulum. Then the pendulum was released and allowed to strike through the specimen. The energy consumed in breaking the sample was calculated from the height the pendulum reached on the follow-through. The maximum reaching height of the pendulum was watched through an angle (β) by an analogue meter that was set with the machine. The impact strength of the specimens was measured by using the following equations:

$$\text{Impact Energy} = \text{WR}\left[\cos\beta - \cos\alpha\right] \quad (3)$$

$$\text{Impact Strength (IS)} = \frac{\text{Impact Energy}}{\text{Area Cross Section}} \quad (4)$$

2.4.4. Water Uptake Test

Water uptake test of the composite samples were carried out in deionized water at room temperature (25°C). The specimens were taken into glass beakers containing 100 ml of deionized water and carried out up to 4 hours. At set time points, those were taken out from the beaker and wiped properly and dried for a single hour at 105°C and then reweighed. The water uptake was measured by a weight difference methodology. The equation for water uptake was as follows:

$$W\% = \frac{Wt - Wo}{Wo} \times 100\% \quad (5)$$

where, Wt indicates the weight of the sample after immersion in water and Wo represents the weight of the sample before immersion.

2.4.5. Soil Degradation Test

JC/UPR and JC/PP composite specimens were buried in non-calcareous soil for different periods of time. After a certain period, those were withdrawn carefully, washed with distilled water and dried at 105°C for 6 hr and kept at room temperature for 24 hr and then the mechanical properties were measured as described before. The used soil had a pH of 5.5. The moisture and send content of the soil were 3.6 and 6.6% respectively.

3. Results and Discussion

3.1. General Comparison on Mechanical Properties of JC/UPR and JC/PP Composites

The mechanical properties (TS, BS, and IS) of JC/UPR and JC/PP composite as well as UPR and PP sheet were evaluated. The highest TS, BS, and IS of JC/UPR composites were found to be 49.01, 88.2 MPa, and 17.9 kJ/m^2 respectively and for JC/PP the highest TS, BS, and IS were found to be 43.64, 69.5 MPa, and 15.31 kJ/m^2 respectively. It was observed from the Table 1 that JC/UPR composite shows 12.31% TS, 26.91% BS, and 16. 92% IS higher value than that of JC/PP composite.

Table 1. Highest Mechanical Properties at 2. 5 mm Thickness of UPR and PP Sheet and Their Composites (46-60 wt% fibre)

Material	Tensile, Flexural and Impact Properties					
	Tensile Properties			Flexural Properties		Impact
	Strength (MPa)	Modulus (MPa)	Elongation at Break (%)	Strength (MPa)	Modulus (MPa)	Strength kJ/m^2
UPR sheet	18. 8	340	55	80. 5	1340	9. 81
PP sheet	21. 8	654	370	29. 2	1070	5. 65
JC/UPR Composite	49. 01	1995	7 ± 0. 3	88. 2	10087	17. 9
JC/PP Composite	43. 64	3055	8 ± 0. 5	69. 5	3405	15. 31

3.2. Comparison of Mechanical Properties of Composites on the Basis of Fibre Loading

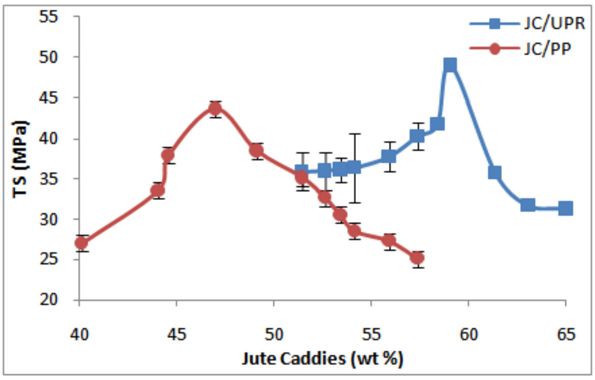

Figure 2. Tensile strength of JC/UPR and JC/PP composites with fibre loading

Figure 2 depicts information about the tensile strength (TS) of various JC/UPR and JC/PP composites on the basis of fibre loading. It was observed from the figure that values of TS of JC/UPR composites were slowly increased with the increase of caddies up to 58.4%. Then it again increased sharply to the maximum point i. e. 49.01 MPa for 59.08% caddies containing composite. During the test, the tensile modulus (TM) at this maximum point was found to be 1995 MPa. After that, TS dropped rapidly to 31.66 MPa for 63.05% caddies containing composite. Then the value of TS stabilized at around 31.45 MPa for the next specimens. On the other hand values of TS of JC/PP composites rose rapidly from 27.01 MPa to the maximum value, 43.64 MPa with the increase of caddies up to 46.96%. The tensile modulus at this maximum point was found to be 3055 MPa in the test. Then the values of TS were found to be straightly declined to the lowest value, i. e. 25.12 MPa for 57.36% caddies containing composite.

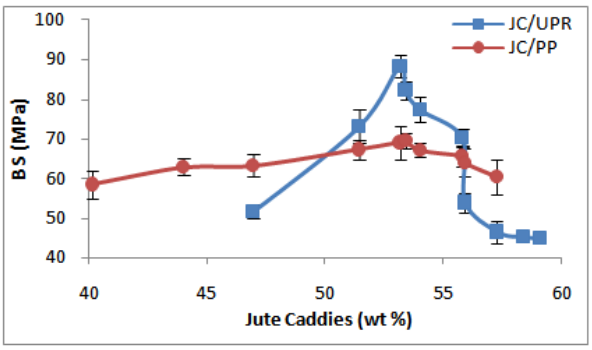

Figure 3. Bending strength of JC/UPR and JC/PP composites with fibre loading

Bending strength (BS) of various JC/UPR and JC/PP composites on the basis of fibre loading is presented by Figure 3. It can be clearly seen from the figure that values of BS and bending modulus (BM) of JC/UPR composites were increased dramatically with the increase of caddies up to 53.17%. The maximum value of BS and BM were found to be 88. 2 and 10087 MPa respectively for 53.17% caddies containing composite and further increasing of caddies content decreased the values.

By contrast, values of BS of JC/PP composites increased linearly with the increase of caddies up to 53.41%. The maximum value of BS and BM were found to be 69.5 and 3405 MPa for 53.41% caddies containing composite and further increasing of caddies content decreased the value.

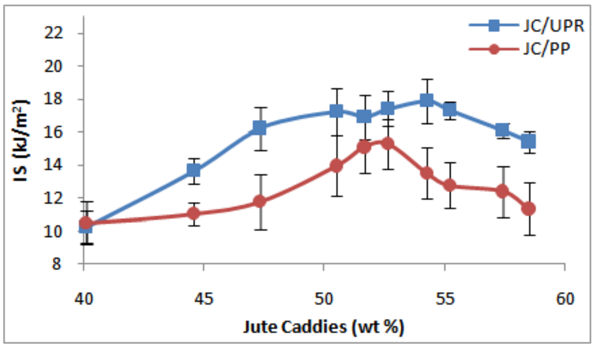

Figure 4. Impact strength of JC/UPR and JC/PP composites against fibre loading

On the basis of fibre loading, Figure 4 provides information about the impact strength (IS) of various JC/UPR and JC/PP composites. From the figure it was observed that values of IS of JC/UPR composites claimed linearly with the increase of fibre content up to 47. 33% in composite. Then it gradually rose from 16.24 kJm^{-2} to 17.25 kJm^{-2} for 50.5% caddies containing composite. After that, it slightly dropped to 16.95 kJm^{-2} for 51.65% caddies loaded composite. However, IS of the composites again started to rise up to the maximum value i. e. 17.9 kJm^{-2} for 54.25% caddies loaded composite. The values of IS then fell minimally to 15.42 kJm^{-2} for the composites of 58.5% caddies. On the contrary IS of JC/PP composite started to rise slowly from 40% caddies content composite and ended by giving the maximum value 15.31 kJm^{-2} for 52.62% caddies containing composite. After that it gradually dropped and finally reached at the lowest value (11.36 kJm^{-2}) for 58.5% caddies loaded composite.

From the above figures we can summarize the result that at lower levels of jute caddies content, the composite shows poor mechanical properties due to higher matrix and poor fiber population which leads to low load transfer capacity to one another. As a result, stress gets accumulated at certain points of the composites and highly localized strains occur in the matrix. At intermediate levels of fibre loading (46-60%), the population of the fibers is just right for maximum orientation and the fibers actively participate in stress transfer. On the other hand, high levels of jute caddies content showed the increased population of fibers, which may lead to agglomeration and stress transfer becoming blocked, and as a result composite property, is again decrease [15].

3.3. Comparison of Mechanical Properties of Composites on the Basis of γ Radiation

The effect of γ radiation on the tensile properties such as tensile strength (TS) of JC/UPR and JC/PP composites was evaluated and illustrated in Figure 5. In this case both types of composites were made with 50% caddies by weight. It can be clearly seen from the figure that with the increase of γ dose, TS of jute-based composite JC/UPR increased from 28.53 (indicated as 0 kGy, i. e., untreated) to 37.05 MPa (at 7.5 kGy) and on the other hand TS of jute-based JC/PP composite increased from 32.46 (indicated as 0 kGy, i. e., untreated) to 39.5 MPa (at 5.0 kGy), and then decreased to 32.2 and 32.5 MPa at 12.5 kGy respectively. It was clearly observed that by using 7.5 and 5.0 kGy of γ dose on the composites, the TS values increased about 29.86 and 21.69% respectively compared to that of untreated composite.

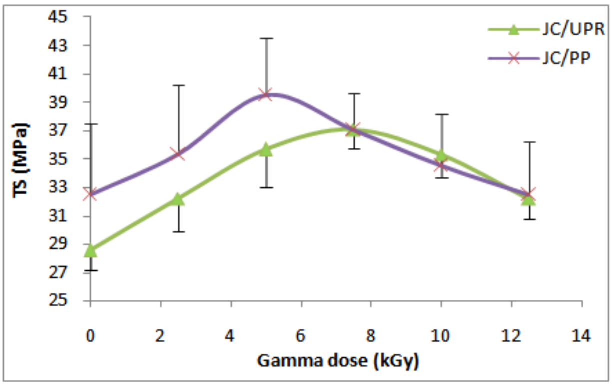

Figure 5. Tensile strength of irradiated JC/ UPR and JC/PP composites (50 wt% fibre)

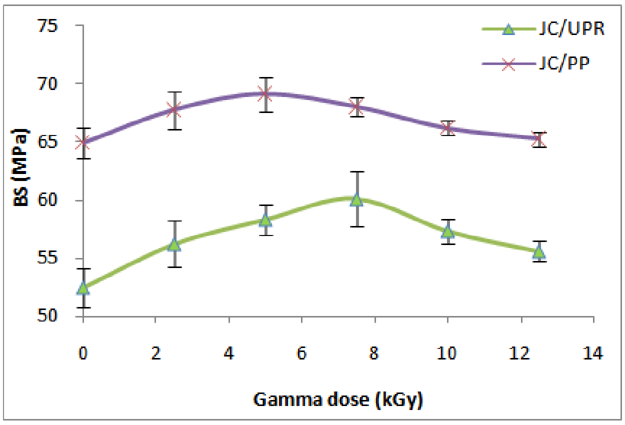

Figure 6. Bending strength of irradiated JC/ UPR and JC/PP composites (50 wt% fibre)

In addition, the effect of γ radiation on the flexural properties such as bending strength (BS) of JC/UPR and JC/PP composites was evaluated successfully. It can be clearly observed from Figure 6 that with the increase of γ dose, bending strength (BS) of jute-based composite, JC/UPR rose from 52.44 (indicated as 0 kGy, i. e., untreated) to 60.1 MPa (at 7.5 kGy). By contrast, BS of jute-based, JC/PP composite climbed from 64.9 (indicated as 0 kGy, i. e., untreated) to 69. 95 MPa (at 5.0 kGy) and then declined to 55.6 and 65.25 MPa at 12.5 kGy respectively. Thus, by using 7.5 and 5.0 kGy of γ dose on the composites, the BS values increased approximately 14. 60 and 7.78% respectively compared to that of untreated composite.

From the Figure 4 and Figure 5 we can conclude that the TS and the BS increased up to certain total doses of gamma radiation and then decreased. Both the TS and BS value of JC/UPR composite were highest at 7.5 kGy gamma dose whereas, for JC/PP composite it was at 5 kGy.

During the gamma irradiation process the polymers (UPR, PP and cellulose) may undergo scission or cleavage i. e. the polymer molecules may be broken into smaller fragment. Subsequent bursting of chemical bonds yields fragments of the large polymer molecules. The free radicals produced by this way may react to change the structure of the polymer which leads to change the physical properties of the materials. It also may undergo cross-linking i. e. the molecules may be joined together into large molecules [16,17,18]. Physical treatment, gamma irradiation also affects the polymeric structure of the fibre and produces active site. Gamma irradiation of PP may result in cross-linking which produces higher mechanical properties up to a certain dose. Active sites inside the PP matrix might be produced by the application of gamma radiation [19].

3.4. Water Uptake Test

The percentage water uptake values of non-irradiated and irradiated JC/UPR and JC/PP composites were plotted against the soaking time in Figure 7 below. It was noticed from the figure that the non-irradiated samples attained highest water absorption 23.5% (JC/UPR) and 6.95% (JC/PP), whereas, uptake of gamma-treated composites were about 6.79% (JC/UPR) at 7.5 kGy and 2.5% (JC/PP) at 5.0 kGy.

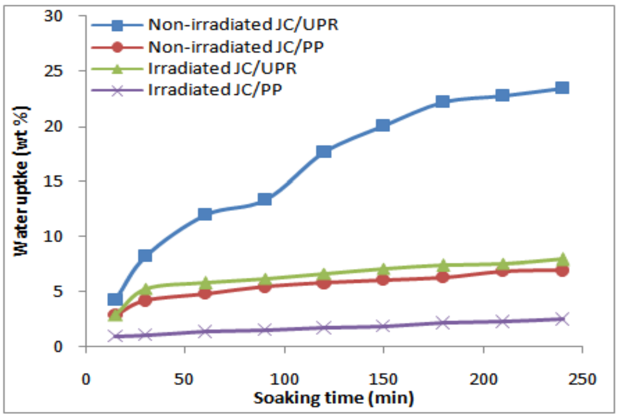

Figure 7. Water uptake of untreated and irradiated composites against soaking time

It was observed for the all types of samples that during the first 30 minutes, water uptake was faster and after that it became slowly except non-irradiated JC/UPR composite. It was clearly shown that the water uptake of the irradiated composites was significantly lower than that of non-irradiated composites. After 4 hours, the water uptake values of non-irradiated, irradiated JC/UPR; non-irradiated and irradiated JC/PP composites were 23.5, 7.95, 6.95 and 2.5% respectively. It was observed that irradiated JC/UPR and JC/PP composites up taken 66 and 64% less water respectively than non-irradiated composite after the test. Percentage of water uptake of the composites mainly depends on the water uptake properties of jute fiber's extent of fiber matrix adhesion. The inter-molecular spaces in the jute fiber are too small to penetrate the water molecule in this region. So the water molecule can only penetrate the amorphous region and get linked with the available hydroxyl (-OH) groups which, is one of the important functional groups in jute fiber, that causes the formation of a large amount of hydrogen bonds and induces their swelling [20]. The decrease of water absorption by post irradiated composites attributed to the fact that gamma irradiation reduced the –OH group as well as increased crystalline regions in jute fibre through cross-linking which in turns decrease amorphous regions.

3.5. Soil Degradation Test

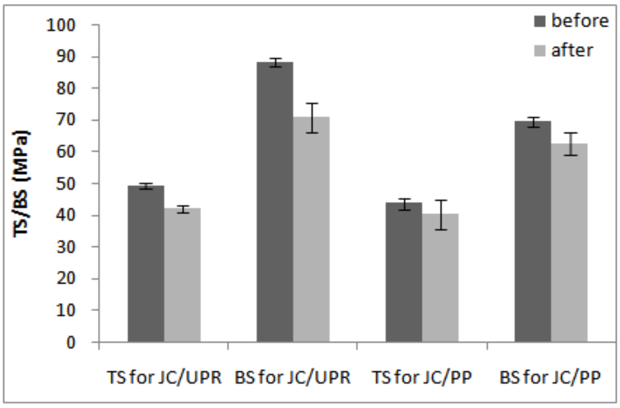

Figure 8. Tensile and bending strength of composites (50 wt% fibre) before and after soil degradation

The specimens of 50% jute content composite were buried in soil for a period of 6 weeks to study the effect of such environmental conditions on the degradability of the samples. Weight loss and tensile as well as bending properties of the samples was periodically measured. In the soil, water diffused into the polymer sample, causing swelling and enhancing biodegradation. The weight loss of the JC/UPR samples was found to be about 25% after 6 weeks, whereas about 19% weight loss was found for JC/PP samples. Figure 8 shows information about the reduction of tensile and bending strength of both types of composites after soil degradation. After 6 weeks of degradation, JC/UPR lost almost 18% where, JC/PP lost almost 8.0% of tensile strength. Moreover, they lost around 25% and 10% of bending strength respectively. From this fact, it was clear that JC/UPR composites showed much of their degradation properties than the JC/PP composites during the soil degradation. Jute is a natural biodegradable fibre and this fibre being cellulose based, it absorbs water within a couple of minutes, indicating its strong hydrophilic character. Cellulose has a strong tendency to degrade when buried in soil [21]. During the soil degradation tests, water penetrated from the cutting edges of the specimens of jute-based composites and degradation of cellulose occurred in jute; as a result, the mechanical properties of the composites reduced impressively.

4. Conclusions

Jute caddies reinforced polyester/polypropylene based low cost polymeric composites were successfully fabricated using traditional hand lay-up method and the physico-mechanical properties of them were evaluated before and after completion different tests and treatment. From this investigation it was found that tensile and bending strength of both types of composites were increased significantly after application of gamma radiation and JC/UPR composite showed better mechanical properties compared to that of JC/PP composite. It revealed that gamma irradiation formed better cross-linking between jute caddies and unsaturated polyester resin compared to jute caddies and polypropylene. The water-resistance properties of both composites were improved almost equally when those were irradiated with suitable doses. Degradation tests of the composites were performed in soil medium, which resulted that JC/UPR composite lost much of its original weight, strength and modulus compared to that of the JC/PP composites.

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