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Effect of gamma radiation on the performance of jute fabrics-reinforced polypropylene composites

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ABSTRACT

Jute fabrics-reinforced polypropylene (PP) composites (50% fiber) were prepared by compression molding. Composites were fabricated with non-irradiated jute fabrics/non-irradiated PP (C-0), non-irradiated jute fabrics/irradiated PP (C-1), irradiated jute fabrics/non-irradiated PP (C-2) and irradiated jute fabrics/irradiated PP (C-3). It was found that C-3 composite performed the best mechanical properties over other composites. Total radiation dose varied from 250–1000 krad and composites made of using 500 krad showed the best results. The optimized values (C-3 composites) for tensile strength (TS), bending strength (BS) and impact strength (IS) were found to be 63 MPa, 73 MPa and 2.93 kJ/m^2, respectively.

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1. Introduction

Composite materials are widely used in civil, industrial and military applications mainly because of their excellent tensile and bending properties. Synthetic fiber-reinforced thermoplastic composites attracted much attention due to its better durability and moisture resistance properties. However, the manufacture, use, and removal of traditional composite structure made of glass, carbon and aramid fibers are considered negative due to growing environmental consciousness. For this reason, alternative reinforcement with natural fiber in composites has gained much attention having low cost, low density, CO_2 neutrality, biodegradability and recyclable nature (Mohanty et al., 2000a,b,c). Among all the natural fibers, jute appears to be one of the most useful, inexpensive and commercially available lignocelluloses fiber. Cellulose is the main component of jute fiber (approximately 64 wt%) (Hassan et al., 2003).The elementary unit of a cellulose macromolecule is anhydro-D-glucose, which contains three hydroxyls (–OH). This hydroxyl form hydrogen bonds inside the macromolecule itself (intra-molecular) and between other cellulose macromolecules (intermolecular) as well as with hydroxyl groups from moist air. Therefore, jute fabrics are hydrophilic in nature and their moisture content can reach 12.6% (Khan et al., 2006). Composites of hydrophilic fiber with hydrophobic or non-polar polymer matrix result in poor mechanical properties compared to pure polymer (Hassan et al., 2005). To overcome these kinds of drawbacks, many attempts, such as physical and chemical treatments, lead to changes in the surface structure and surface energy of the fibers. However, for jute to survive in the face of hard competition with synthetic products, it must be improved in its physical properties to retain its inherent status. To prevail over the drawbacks of jute fiber, high-energy gamma radiation has been employed successfully for significant physical and chemical changes as well as changes in surface structure and surface energy of the fibers. Many researchers are working on jute fibers and jute fiber-reinforced composites. Some jute reinforced composites with urethane oligomer under gamma radiation were prepared and characterized (Basher et al., 1996). Khan et al. also prepared and characterized jute–polycarbonate and jute–biopol composites and reported probable alternative of synthetic composites (Khan et al., 2003 and Khan et al., 2005). Several reports have documented where jute fibers are used as reinforcement in thermoplastics like polyethylene and polypropylene (PP) and thermo-sets like unsaturated polyester and epoxy resin (Mohanty et al., 2000a,b,c; Ali et al., 1997, Khan et al., 2001a,b; Ali et al., 1999; Mohanty and Misra, 1995; Joseph and De Carvalho, 2000; Wolcott, 1993; Czvikovszky, 1995). The influence of ionizing radiation on polymers, particularly gamma radiation, has been studied quite extensively over the past few decades. Ionizing radiation such as gamma radiation is known to deposit energy in solid cellulose by Compton scattering and the rapid localization of energy within molecules produced trapped macrocellulosic radicals. The radicals thus generated are responsible for changing the physical, chemical and biological properties of cellulose fibers (Jochen and Andrzej, 1997; Saheb and Jog, 1999; Valdez-Gonzalez et al., 1999). Polypropylene is an amorphous thermoplastic

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polymer and widely used as engineering thermoplastic, because it possesses several vital and useful properties such as transparency, high mechanical strength, high heat distortion temperature, low-moisture pickup and good dielectric properties. PP is also very suitable for filling, reinforcing and blending. PP with fibrous natural polymers of biomass origin is one of the most promising routes to create natural–synthetic polymer composites (Lua and Netravali, 1999; Benedeto et al., 1989; Karmaker and Hinrichsen, 1999).In this investigation, jute fabrics and PP sheets were pretreated using gamma radiation varying total doses from 250 to 1000 krad, and then composites were fabricated by heat press. Effect of gamma treatment of reinforcing agent and matrix material on composites was investigated. Mechanical and electrical properties of the composites made of different combinations of gamma treatment were measured and tried to found the effect of gamma radiation on the composites. Simulated weathering, water uptake and electrical properties of the different types of composites were investigated and compared to the untreated composites.

2. Experimental

2.1. Materials

Jute fabrics (bleached commercial grade made of tossa jute) were obtained from Bangladesh Jute Research Institute (BJRI), Dhaka, Bangladesh. Polypropylene was collected from Polyolefin Company Ltd., Singapore.

2.2. Preparation of PP sheets

Polypropylene sheets of 0.25–0.30 mm thicknesses were prepared by heat press (Carver Inc. USA with hydraulic unit model 3925) at 190 °C for 5 min between two steel plates under a pressure of 5 tons.

2.3. Irradiation

Jute fabrics and PP sheets were irradiated using a Co-60 gamma source. In gamma radiation, a Co-60 source (25 kCi) 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. Jute fabrics and PP sheets were pretreated with gamma radiation varying different doses (250–1000 krad).

2.4. Fabrication of composite

Composites were prepared by sandwiching four layers of jute fabrics between five layers of pre-weighted PP sheets at 190 °C for 5 min between two steel plates under a pressure of 5 tons. The composite was cooled to room temperature, then cut to the desired size using band saw and packaged in a polyethylene bag and then kept in the desiccators prior to further testing.

2.5. Mechanical tests

The tensile properties of PP sheets and composites were determined directly with the help of universal testing machine (INSTRON, model 1011, UK) using gauge length of 20 mm and crosshead speed 10 mm/min. Tensile and bending properties were carried out following DIN-53455 and DIN-53452 standards, respectively. Charpy impact strength (IS) was measured by an impact tester (MT-3016) according to the DIN EN ISO 179 standard in the flat wise, unnotched mode. Test samples were conditioned at 25 °C and 50% relative humidity for several days before testing and all the tests were performed under the same conditions.

2.6. Accelerated weathering aging

Both treated (C-3) and untreated (C-0) composite samples were treated using simulated weathering tester from Q-panel Co (model QUV, USA). The weathering testing was performed in alternating cycles of sunshine over 4 h (65 °C $\pm$ 2 °C) and condensation for 2 h (45 °C $\pm$ 2 °C). This aging test was carried out for 600 h.

2.7. Water uptake

Both composites (C-0 and C-3) were used to determine water uptake by soaking the samples in a static water bath at room temperature. The wet sample was wiped several times using tissue papers. Water uptake was calculated from the mass gain of the samples after the treatment. The amount of water uptake was monitored periodically up to 30 h.

2.8. Electrical tests

For the measurement of dielectric properties (dielectric constant and loss tangent), composite (C-0 and C-3) samples were cut into very small pieces (rectangular shape), and then powdered and made tablets. These tablets were used for dielectric measurement. A Marconi Universal bridge (TF1313A) operating at 10 kHz was used for measuring dielectric properties. For the measurement of the temperature dependence dielectric constant, the sample was placed in the dielectric cell and the cell was placed inside a cylindrical furnace. Varying the input power to the furnace varied the cell temperature. Capacitance (C) and loss tangent ($\tan\delta$) of the samples were measured at different temperature with the help of a chromel–alumel thermocouple, which is very sensitive. Thermo electromotive force (e.m.f.) was measured by a digital multimeter (DL-706) and the corresponding temperature was found out from the calibration chart. The dielectric constant and loss tangent of the composites were measured by using bridge technique (two-electrode method) over the temperature range from 50 to 120 °C at frequency 10 kHz.

3. Results and discussion

3.1. Tensile strength (TS) and bending strength (BS)

Jute fabrics-reinforced PP composites were prepared by compression molding where jute content was about 50% which was optimized earlier (Khan et al., 2008). In order to make a systematic study of the effect of gamma radiation, three types of composites were made using: (i) non-irradiated jute fabrics/irradiated PP (C-1), (ii) irradiated jute fabrics/non-irradiated PP (C-2) and (iii) irradiated jute fabrics/irradiated PP (C-3). Radiation treatment (total gamma dose) varied from 250–1000 krad. The effect of gamma radiation on the mechanical properties (TS and BS) of PP sheet was also monitored. The results are shown graphically in Figs. 1 and 2. From the Fig. 1, it is clear that with the increase of total gamma dose, the TS of the PP sheet increased from 30.15 (indicated as 0 krad, i.e., untreated) to 38.33 MPa (500 krad) and then decreased to 34.13 MPa at 1000 krad. So, by using 500 krad of gamma dose on the PP sheet, the TS values increased about 27% compared to that of untreated PP sheet. For all the composites made of different combinations of jute and PP (C-1, C-2 and C-3), TS values increased up to 500 krad then

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