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Preparation and Effect of Gamma Radiation on The Properties and Biodegradability of Poly(Styrene/Starch) Blends

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HIGHLIGHTS

- The irradiated PSty/10 wt% Starch blend by dose 5 kGy has modified properties.
- The irradiated PSty/10 wt% Starch blend can be used as packaging material.
- Total dose of 20 kGy increase the biodegradability due to great degradation effect.
- The degradation in agricultural soil is slightly higher than that in desert soil.
- Radiation processing will prove to be a good alternative to chemical modifications.

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ABSTRACT

Biodegradable blends based on Poly(styrene/starch) Poly(Sty/Starch) were prepared by the casting method using different contents of starch in the range of 0–20 wt% aiming at preparing disposable packaging materials. The prepared bio-blends were Characterized by Fourier transform infrared (FTIR), swelling behavior, mechanical properties, thermogravimetric analysis (TGA), and scanning electron microscopy (SEM). It was found that the swelling behavior slightly increased with increasing starch content and not exceeding 7.5%. The results showed that by increasing irradiation dose up to 5 kGy, the mechanical properties of the prepared PSty/10 wt% Starch blend film modified than other blend films, and hence it is selected. Also the water resistant increased, by irradiation of the selected PSty/10 wt% Starch blend film. The intermolecular hydrogen bonding interaction between Starch and PSty of the PSty/10 wt% Starch blend film promote a more homogenous blend film as shown in scanning electron microscopy (SEM). The prepared Poly(Sty/Starch) blends with different compositions and the selected irradiated PSty/10 wt% Starch blend were subjected to biodegradation in soil burial tests for 6 months using two different types of soils; agricultural and desert soils, then analyzed gravimetrically and by scanning electron microscopy (SEM). The results suggested that there is a possibility of using irradiated PSty/10 wt% Starch at a dose of 5 kGy as a potential candidate for packaging material.

1. Introduction

After polyolefins, Polystyrene is the most widely used polymer in both industry and everyday life (Sheikh et al., 2013; Kaczmarek et al., 2004). This is because of its low cost, easy production and appreciable properties such as a good balance of rigidity and transparency. Polystyrene (PSty) is a synthetic hydrophobic polymer with high molecular weight, it is neither biodegradable (Schlemmer et al., 2009; Arvanitoyannis and Biliaderis, 1999) nor environmently recycled (Tolinski, 2012).

Synthetic polymers are widely used as packaging materials because of their good mechanical properties, thermal stability, their performance as good barriers to carbon dioxide, oxygen and aromatic compounds, and their wide availability and relatively low cost (Sam et al., 2014).

The cost associated with recycling of plastic packaging is often higher than that of producing virgin plastics. Consequently, several

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thousand tons of goods, made from plastic materials, are sent to the environment every day which increase the amount of waste products (Sam et al., 2014).

In the past decades, there has been an increasing interest in the use of bioplastics and biodegradable polymers (Ahmad et al., 2012; Arvanitoyannis et al., 1998; A. El-Rehim et al., 2004; Morancho et al., 2006; Nakamura, et al., 2005; Ramis et al., 2004).

Starch is used as filler because it is a natural polymer, abundant, inexpensive and a renewable resource. It is degraded by microorganisms and it is suitable for blending with synthetic polymers (Ghazali et al., 2013). The addition of starch to Polystyrene plastics has been developed as a technique to achieve biodegradability. As micro-organisms consume the surrounding starch, the bioplastic loses its structural integrity, and this leads to enhancing the biodegradation mechanisms and deterioration of the mechanical properties occur (Kiatkamjornwong et al., 1999).

The use of high energy gamma rays has been recognized to develop or modify polymers such as Polystyrene /starch blend through crosslinking (Ahmad et al., 2012; Makuuchi and Cheng, 2012; IAEA Report, 2014). Therefore, the aim of this study is to prepare biodegradable Polystyrene by addition of starch with low concentration ranging from 0 to 20 wt%. Furthermore, the effects of irradiation at low doses of 0, 10, 15 and 20 kGy on the properties of the prepared polystyrene /starch (PSty/Starch) blends were investigated. The prepared and modified Poly(Sty /Starch) blends were subjected to biodegradation in soil burial tests for 6 months using two different types of soils; agricultural and desert soils causing the finished plastic material to lose its integrity and be reduced to particles, small enough to be of minimal damage to the environment (Schlemmer et al., 2009; Ahmad et al., 2012; Kollengode et al., 1996).

2. Experimental

2.1. Materials

The polymeric matrix used was high strength Polystyrene (PSty) crystals, MW approx. 400k, purchased from Denka Styrol Singapore Private Limited, Singapore, without any additives or pigments, Maize starch (amylose, 27% and amylopectin, 73%) used throughout this study was supplied by the Egyptian Company for Starch and Glucose, Cairo, Egypt. Benzene was used as a solvent and was provided by El-Nasr Pharmaceutical chemicals, Egypt.

2.2. Preparation of Poly(Sty/Starch) Blend

In this study, Polystyrene/Starch blend Poly (Sty/Starch) was prepared by dissolving 6 g of PSty in 110 ml of benzene as a solvent with stirring at 80 °C then different concentrations of starch 5,10,15,20 (wt%) were added and casted on Petri dish of 25 cm diameter. The obtained blend films were left to dry at room temperature and cut into small films of 2 cm × 2 cm dimension.

2.3. Gamma irradiation

Irradiations at doses of 0, 5, 10, and 20 kGy were performed at a dose rate of 0.65 Gy /s in air at the ^{60}Co Gamma Cell Facility of the National Center for Radiation Research and Technology, Cairo, Egypt.

2.4. FTIR spectroscopic analysis

The infrared analysis was carried out using Fourier transform infrared spectroscopy FTIR-4100 spectrophotometer purchased from Jasco, Japan, over the range of 400–4000 cm^{-1}. The analysis was performed at the Micro-analytical Center, Cairo University, Egypt.

2.5. Mechanical testing

Mechanical properties of the prepared Poly(Sty/Starch) blend films including tensile strength and elongation at break points were analyzed at room temperature using Mecmesin (model 10-I, England) at a crosshead speed of 5 mm/min. and load 250 N according to the ASTM D-638 standards. The recorded value of the tensile strength and elongation at break is average of three measurements.

2.6. Swelling properties

The pre-weighted dry samples were immersed in deionized water for the required time interval at room temperature, quickly dried with filter paper and then weighed. The swelling (%) was calculated as follows:

$$\text{Water Uptake}\,(\%) = \frac{W_s - W_o}{W_o} \times 100 \quad (1)$$

W_s is the weight of the sample in the swollen state and W_o is the initial weight of the dry sample.

2.7. Thermogravimetric analysis (TGA)

Shimadzu TGA system of type TGA-50 Thermogravimetric analyzer was used, the TGA flow rate of pure nitrogen of 30 ml/min and the heating rate was 20 °C/min, from the ambient temperature up to 600 °C. The analysis was performed at the Micro-analytical Center, Cairo University, Egypt.

2.8. Biodegradation test

The aim of this test is to determine the effect of starch concentration and gamma irradiation on the biodegradation behavior. Biodegradation studies of the blank PSty, Poly(Sty/Starch) with different concentrations of starch and the selected irradiated PSty/10 wt% Starch samples were performed in soil burial tests for 6 months using two different types of soils; agricultural and desert soils. The soil was kept moist with water after every day to overcome the water loss by evaporation. The samples were removed, washed with distilled water and dried to a constant weight at 40 °C and analyzed gravimetrically.

The weight loss of the blends with concentrations of starch was used to indicate the degradation rate in the two soil burial tests. The percentage weight loss after 6 month was determined as follows (Phetwarotai et al., 2013; Sharma et al., 2014):

$$\text{Weight loss}\,(\%) = \frac{W_o - W_f}{W_o} \times 100 \quad (2)$$

Where W_o is the original weight of the sample and W_f is the decrease in weight after 6 months of burying.

The remaining weight (%) was calculated for each blend composition and the selected irradiated PSty/10 wt% Starch blend as follows (El-Arnaouty et al., 2008):

Remaining weight (%)=100–(the weight loss of the sample after the period of burying)

$$\text{Remaining weight}\,(\%) = 100 - \frac{W_o - W_f}{W_o} \times 100 \quad (3)$$

Where W_o is the original weight of the sample and W_f is the decrease in weight after the period of burying.

The degradation rate/week (Br/w%) was calculated by the