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Plastic Films Based on Waste Expanded Polystyrene Loaded with Bagasse Powder for Packaging Applications

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Abstract

Biocomposites of waste expanded polystyrene (EPS) with sugarcane bagasse (SCB) powder were prepared through casting technique to produce plastic films. EPS was plasticized by using dioctyl phthalate (DOP) to overcome the rigidity of the recycled polystyrene and obtain flexible films. The loadings of bagasse powder were (5, 10, 15 and 20) wt. % with respect to polystyrene. The mechanical properties were maintained although some variations arose after loading polystyrene with bagasse. The hardness of these composites increased over that of plasticized polystyrene. The thermal stability of the prepared composites did not deteriorate upon loading EPS with SCB powder. The investigated EPS/SCB films displayed the capability to absorb moisture and to be used in packaging applications.

Keywords: Expanded polystyrene; Bagasse; Packaging applications; Plastic films; Biocomposite.

1. Introduction

Used expanded polystyrene (EPS) exists among the major plastic wastes in the municipal trash. It is a solid foam of polystyrene. EPS shares in different applications due to its advantages comprising its low cost, low density, chemical resistance and insulation [1-3]. Moreover, EPS is employed in preserving and packaging products [4]. Expanded polystyrene is a hydrophobic polymer. Nevertheless, this polymer possesses a relatively short usage span of less than a year. A huge amount of EPS is present and forms a burden on the environment, needing to be recycled. Polystyrene is able to be mechanically reused with other materials. Meanwhile, expanded polystyrene demands either mechanical or solvent-based treatment for de-foaming with a decrement in its volume to be easily processed. The utilized solvents in the de-foaming step do not lead to degenerate the polymeric chains [5]. Polystyrene blocks can be blended with other plastics such as polyethylene terephthalate, polypropylene and polyethylene [6,7]. Poor adhesion arises in the resulting blends due to incompatibility. Compatibilizers are highly recommended to enhance the interfacial adhesion and compatibility with acceptable physical properties for the resulting blends. Hence, stress is able to transfer through the different polymeric components of the blends [8-10]. Fillers are classified as a major component in composites, mainly the polymeric ones. They are introduced into polymeric substrates to minimize the cost and reinforce with enhancing the properties [11,12]. Fillers comprise metals, clays and glasses [13-15]. Moreover, different carbon allotropes can be employed as beneficial fillers in polymers [16-18]. They pack the cavities in the polymeric networks. However, in some applications, porous polymeric structure are favored for successful applications [19-21]. Utilizing waste cellulosic materials in industrial implications is a smart track as they are abundant within the environment through the form of agricultural remains. There are huge amounts of sugarcane bagasse (SCB) growing annually. These biodegradable, abundant, and low cost biomass

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substrates are successful materials to produce beneficial products from the economic and environmental points of view. Sugarcane bagasse with its homogeneous structure is used as a reinforcing material filler in polymeric composites.

Biocomposites are polymeric ones reinforced with fillers of biological nature. Various studies investigated preparing and characterizing biocomposites. Polypropylene, polyethylene, were loaded with natural fibers such as polylactic acid, and starch [22,23]. The mechanical properties of biocomposites based on polypropylene and coriander straw were maintained without considerable decrease. Recycling of biocomposites based on polylactic acid (PLA) and sisal fibers showed reduced mechanical properties after the third recycling cycle [24]. Introducing bagasse to a polypropylene (PP) through injection molding technique [25] displayed a boost in the mechanical behavior of the biocomposites. This increase is referred to the basic treatment of bagasse fibers. The mechanical and thermal and morphological properties of recycled polypropylene-acrylonitrile rubber blend (PP-NBRr) with silinated bagasse fibers showed an improvement in mechanical properties and thermal stability of the composites [26]. Cellulosic materials are widely used in packaging applications. The packaging efficiency of crosslinked polyvinyl alcohol (PVA)/bagasse film was enhanced expressing high mechanical and (moisture) water-resistance properties. This improvement was achieved through dissolving bagasse fibers in PVA dispersed in the cellulose matrix in the presence of epichlorohydrin as crosslinker [27]. The prepared composite films showed an enhanced water resistance feature to be suitable for food packaging application.

The aim of the present work is to utilize waste expanded polystyrene (EPS) with sugarcane bagasse powder in composing plastic films to be applied as a packaging material. The presence of bagasse in the prepared biocomposites through casting technique extends the ability of absorbing moisture for the packaged products in these films.

2. Materials and methods

2.1. Materials

Waste expanded polystyrene (EPS) was collected from consumed products. Bagasse was supplied from sugarcane cultivated in Minya - Egypt. Tetrahydrofuran (THF) and dioctyl phthalate (DOP) (99% purity) were provided from Aldrich, Germany.

2.2. Instrumentation

JASCO FTIR-6100 FTIR spectrometer was employed for Fourier transform infrared (FTIR) spectral analysis. The surface morphology of the prepared samples were examined with scanning electron microscopy (SEM); JEOL JSM5400 high resolution (Shimadzu.Co., Japan). Fractured surfaces of the tested samples were coated with thin film gold before investigation. The analysis was carried out by a Lloyd instrument (LR10 K; Lloyd Instruments, Fareham, UK) with a 100-N load cell to evaluate the tensile properties tests of the investigated samples. The crosshead speed was 20 mm/min. at 25 °C. Hardness property was performed using samples with flat surfaces. Baxlo-type D Durometer was used for implementing the measurements according to ASTM D 2240. Thermogravimetric analysis (TGA) from Perkin-Elmer were employed. The samples were encapsulated in aluminum pans and heated under nitrogen atmosphere with a heating rate of 10 ^{o}C/min.

Water uptake percentage was determined by estimating the moisture absorption capacity for the prepared samples. This was carried out by introducing the tested samples at known weights in distilled water at 25 °C for 24 h. The samples were blotted and weighed. Water uptake % (W_u %) is indicated according to the following equation:

$$W_u = [(W_f - W_i)/W_i] \times 100$$

where, W_f: Weight of the sample after being placed in water, W_i: initial weight.

2.3. Preparation of the plastic films

Sugarcane bagasse (SCB) was collected from sugarcane residues after being squeezed. SCB was cleaned, dried then grinded to produce bagasse powder in the form of micro-sized particles of average size 25 μm. Expanded polystyrene (EPS) was dissolved in (THF) followed by adding dioctyl phthalate (DOP). The later was introduced to plasticize EPS, then casted and dried to obtain a polystyrene film. Composites of polystyrene with various bagasse powder loadings (5, 10, 15 and 20) wt. % of polystyrene were prepared followed by casting in Petri dishes.

3. Results and Discussion

Fig. 1 represents the FTIR spectra of EPS and EPS/SCB composite. In Fig. 1a, some characteristic bands denoting to C-H (stretching) arise at 3417 cm^{-1}, 2928 cm^{-1}, 2917 cm^{-1}, 2342 cm^{-1} and 1446 cm^{-1} for polystyrene. Moreover, other peaks referring to C=C (stretching) at 1724 cm^{-1}, 1446 cm^{-1}. They point to the linkage of CH_2 group with C=C bond. The peaks of C-O and C-O-C bonds appear at 1118 cm^{-1} and 1023 cm^{-1} respectively. In Fig. 1b, the spectrum of the cellulosic component; sugarcane bagasse shows an absorption peak with a noticeable decrease in the intensity of the stretching (O-H) peak at 3105 cm-1. It designates the intramolecular hydrogen bonds of cellulose. This decrement in the

peak due to the mechanical treatment upon grinding [28]. The characteristic peaks of sugarcane bagasse appear at 2861 cm^{-1} and 2927 cm^{-1} for C-H (stretching). Another peak for C-O is located at 1724 cm^{-1}. It indicates the binding of ester and acetyl groups of hemicellulose and cellulose. The aromaticity of lignin can be observed at 1724 and 1446 cm^{-1}.

SEM micrographs for EPS and EPS/SCB composite are illustrated in Fig. 2. The fractured surfaces of the investigated samples can describe the morphology of these polymeric substrates. In Fig. 2a, the surface of plasticized EPS seems as a smooth one, expressing an exemplary fracture behavior.

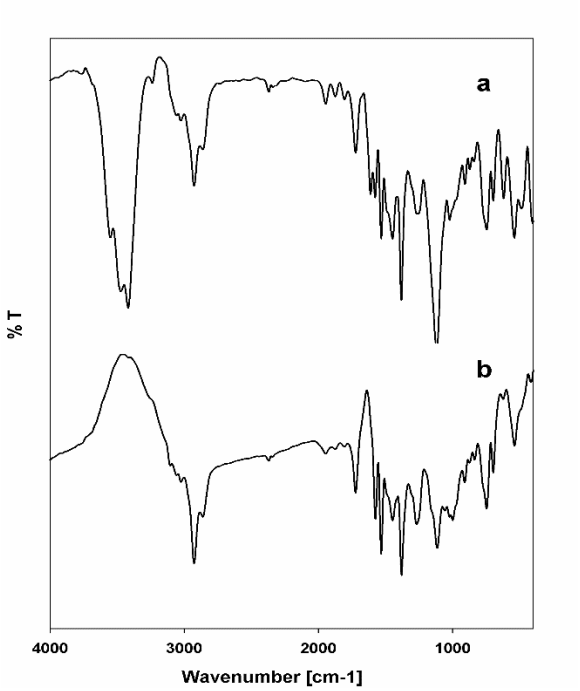

Fig. 1. FTIR of a) Expanded polystyrene (EPS) b) EPS loaded with bagasse.

Upon introducing the sugarcane bagasse powder to the polymeric matrix of expanded polystyrene, some morphological changes become apparent as shown in Fig. 2b. A uniform dispersion for the cellulosic filler extends through the major polymer network. The homogeneity demonstrates slight roughness in the surface without significant agglomerations. Some gaps may be observed resulting from the exerted stress at the interface between EPS and SCB powder. The consolidation of the cellulosic powder with EPS augments the loading capability beside its intercalation into the polymeric domain.

The tensile properties of EPS/SCB biocomposite samples loaded with various concentrations of the cellulosic waste powder were investigated. Fig. 3 illustrates the tensile strength (TS) appearing to decrease steadily with increasing SCB content till reaching the highest concentration of 20 wt. %. The reduction in the tensile strength values did not show complete deterioration. They were in the in the range of 0.5 MPa upon increasing SCB content in polystyrene matrix. This decrement may be referred to the existence of bagasse in the polymeric matrix without adding compatibilizers.

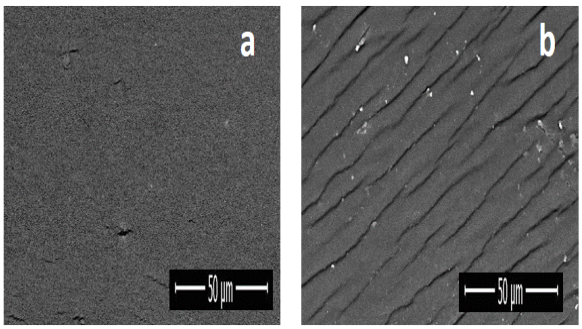

Fig. 2. SEM of a) EPS b) EPS loaded with sugarcane bagasse powder.

SCB has a hydrophilic nature with porous structure. Subsequently, they did not show reinforcing effect. The elongation at break % for EPS and its composites with bagasse are demonstrated. The elongation values diminished by increasing SCB content in the investigated biocomposites. This feature may be correlated to some stiffness that may arise from SCB inside the plasticized polymeric matrix. The elastic modulus behavior of EPS/SCB films. A similar character to the previously mentioned mechanical results arises upon increasing the SCB loadings. The decrement in elastic modulus is due to incomplete adhesion between PS and SCB. At higher concentrations of bagasse, tensile modulus values are negatively affected with some agglomerations starting from 15 wt. % of SCB inside PS matrix.

The hardness values of EPS and EPS/SCB biocomposites are demonstrated in Fig. 4. They were tested by a shore D hardness durometer, showing a steady increase upon increasing the bagasse concentration in the investigated samples. SCB powder seems to be hard enough to increase the hardness of plasticized EPS. It is assumed that both cellulose and hemicellulose share in acquiring hardness to bagasse. The hardness boosts denoting to an augmenting resistance of polymeric matrix against deformation [3]. This behavior takes place as more bagasse is introduced. Hence, the composite turns to be harder with enhanced hardness.

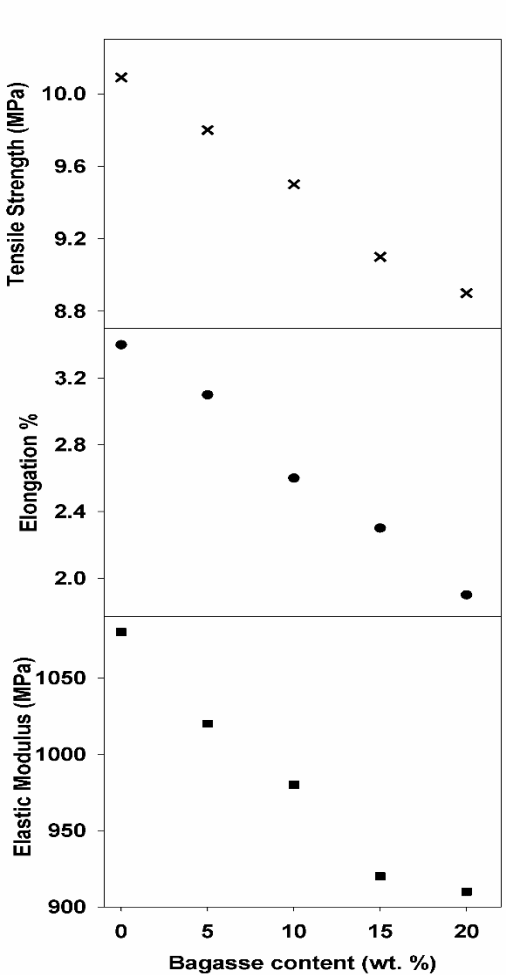

Fig. 3. Tensile properties of EPS and EPS/Bagasse biocomposites: Tensile Strength, Elongation at break % and Elastic Modulus.

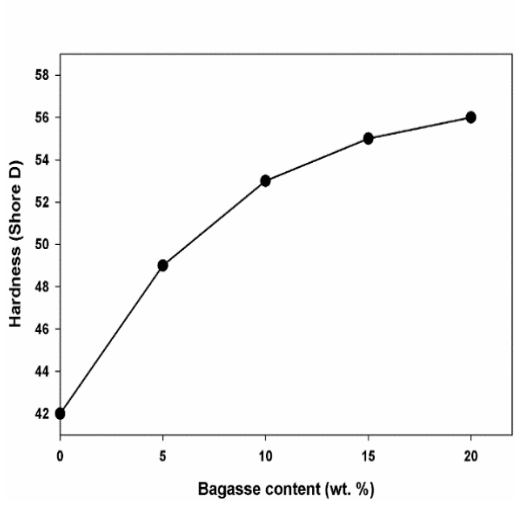

Fig. 4. Hardness of EPS loaded with various contents of bagasse.

Thermogravimetric analysis (TGA) is appointed for pursuing the thermal stability of the tested samples. Some variations occur in the weight as the sample is gradually heated. In Fig. 5, (TGA) thermograms of EPS and EPS/SCB composite, demonstrates weight loss of plasticized EPS when referred as the control sample to observe thermal changes after introducing SCB. There is a noticed decomposition for EPS at 253 ^{o}C. This stage is followed by a thermal cracking of the polyene molecules with the decomposing plasticizer [29,30] at 427 ^{o}C showing a weight loss of nearly 80% of the original weight. Upon proceeding over this temperature, almost the polymeric matrix totally degrades. A similar trend can be observed for the sample of EPS/SCB but a relatively lower temperatures with lower thermal stability than EPS. A primary decomposition stage takes place at 115 ^{o}C. This behavior can be correlated to the volatile content in SCB by losing 3% of the sample weight [31]. The following step is the degradation of lignin and holocellulose [26,32]. Afterwards, the ignition of char and lignin residues occurs. TGA thermograms indicate that the main weight loss and decomposition occurred at higher temperature for EPS than EPS/SCB composite. This feature may be correlated to the observation that EPS as a plastic material is deficient in water. Moreover, plastics have simpler structure when compared with biomass. The thermal stabilization of EPS/SCB composite is lower than that of EPS but still maintained without complete deterioration.

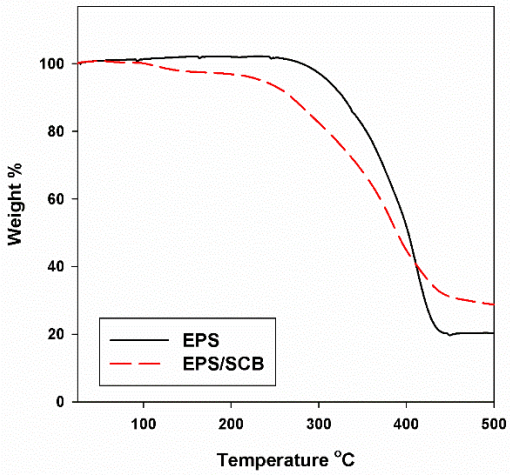

Fig. 5. TGA thermograms of EPS and EPS/Bagasse.

The tendency of the tested samples for the prepared films to absorb moisture or humidity has been investigated and displayed in Fig. 6. This test has been carried out at 25 ^{o}C. It is represented with

the average of 3 successive specimens for each composite. Some changes are observed in the prepared composites loaded with SCB up to 20 wt. % when compared with the reference sample of EPS. A proportional increase in water uptake values is noticed upon increasing bagasse contents. This behavior can be correlated to the hydrophilic nature of bagasse and its ability to absorb water. It leads an increase in the free volume with higher susceptibility to ingest moisture. Hydrogen bonding takes place between water molecules and the hydroxyl groups of cellulose in bagasse. The promising results of water uptake adequacy for the tested EPS/SCB films paves the way for a possible application of these films to be applied in packaging application with the tendency to absorb moisture form the packed products.

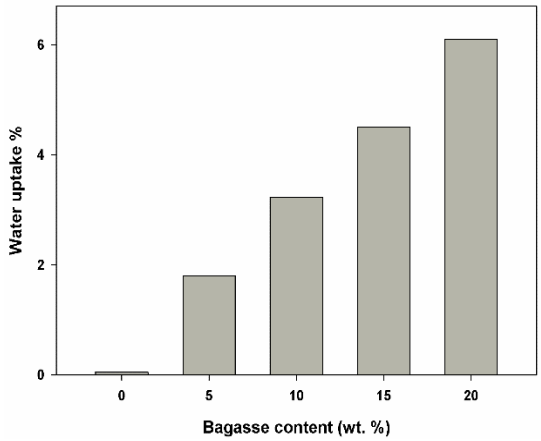

Fig. 6. Water uptake % of EPS loaded with various contents of bagasse.

4. Conclusions

Biocomposite plastic films based on waste expanded polystyrene and sugarcane bagasse (SCB) powder were prepared through casting technique. The cellulosic powder in these composites varied in concentration to be (5, 10, 15 and 20) wt. % of polystyrene. The latter was plasticized with dioctyl phthalate (DOP) to avoid toughness and rigidity upon the recycling process. Hence, flexible polymeric films were obtained. The morphological properties showed homogenous surface for the investigated samples after loading them with SCB. The mechanical properties and thermal stabilities were maintained without degeneration in the presence of the used cellulosic powder. The styrene-based biocomposites showed their ability to absorb water due to the presence of sugarcane bagasse powder. The latter behavior favors these films to absorb moisture upon being used in packaging applications.

Conflicts of Interest

The authors declare no conflict of interest.

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