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RESEARCH ARTICLE

PLA-SiO_2 nanocomposite films: morphological and mechanical properties and specific end-use characteristics

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ABSTRACT

Objective(s): Application of eco-friendly materials like poly lactic acid (PLA) is increasing, to reduce environmental pollutions. In this research, the effect of silicon dioxide 1%, 3% and 5% nanoparticles on morphological, mechanical and chemicals interaction (FTIR) of PLA film was studied.

Materials and Methods: Scanning electron microscope (SEM) was used, to consider morphological structure of nanocomposites. Mechanical characteristics of films, measurement of tensile strength, elongation at break point and Yong modulus also were considered by using tensile device and ASTM D 882. The FT-IR spectrum of films with PERKIN ELMER 1650, FT-IR spectrophotometer was recorded.

Results: Morphological evaluation of PLA composite strings shows desirable and steady distribution of nanoparticles for the sample with 1 percent weight of Silica volume and by increasing Silica contents from 1 to 5 percent, nanoparticles start to form mass. Comparison of average of tensile resistance, elongation at break point and Young modulus in pure PLA film with PLA film including 1% SiO_2 shows insignificance of average of these groups (P>0.05). In the consideration, FTIR shows proper distribution of nano-SiO_2 dioxide in film composites and connection is created and doesn't have difference with pure PLA.

Conclusion: Performed considerations show that PLA films containing SiO_2 have proper potential for application in packaging mechanically.

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INTRODUCTION

Presently, there is ever-increasing tendency to use eco-friendly materials with the purpose of replacing non-biodegradable materials that results to reduction of environmental pollution. The pollution is formed because of high number of plastic wastes. From biodegradable materials, we can point to poly lactic acid. PLA has high potential for replacing polymers based on oil combinations because of thermoplastic nature, biodegradation and biocompatibility nature, mechanical resistance and high elastic modulus and easy productivity. Poly lactic acid (PLA) is thermoplastic polyester with linear chain that is produced from renewable sources. Lactic acid, as a monomer forming PLA, is created from fermentation of herbal raw materials like corn. Despite numerous advantages of PLA in comparison with other biopolymers, its application in industry and competition with industrial polymers faces with different main challenges such as high water vapor and gas permeability, low glass transition temperature (Tg), weak thermal resistance and fragility, this problem shows inevitable need to modification and improvement of features before application [1,2].To conquer these problems, we can use

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approaches like application of proper conditioners, combination with other polymers, optimization of crystallization conditions and use of proper additives for producing different composites. Using nanoparticles and producing nanocomposite for improvement of polymer features are studied because of high variety and efficiency of the particles. Composite is a massive object or a mass that at least has two separate materials with complementary structure. Nanocomposite also is a special category of composites that at least one of their component is in nano size. Generally, the purpose of using nanocomposites is increase of mechanical resistance, weight reduction, increase of resistance against heat, better prevention from UV, CO_2 and O_2 and moisture, better recyclability compatibility and higher protection of the product [3]. From nanoparticles, we can point to nano-Si dioxide. Silicon dioxide or Si is the most abundant material that forms earth crust. The combination has a structure like diamond with chemical formula of SiO_2. It is a crystal and white material and its melting and boiling point is relatively high. Moreover, it is found in environment in two figures of crystal and amorph. SiO_2, with resistance against high heat and melting point of 1750 °C, can be used for improving resistance against PLA heat. Approximately, all authors that reported combination of inorganic silicon dioxide with PLA used it for creating block, film or plate not fiber or string figure. Consequently, PLA/SiO_2 composite string should be performed. Moreover, nanoSiO_2 has protective functions of environment and it is safe and nontoxic. Therefore, PLA/SiO_2 composite string has eco-friendly nature. On the other hand, nanoSiO_2 has low price that can reduce the cost of composite string. Moreover, color of nanoSiO_2 is white, so composite string is explicit and can be colored with all colors [4]. The aim of this study was to investigate the morphological, mechanical properties and chemicals interaction of silicon dioxide nanoparticle poly lactic acid films.

MATERIALS

In this study, Poly (lactic acid) (PLA) films with 0%, 1%, 3% and 5% silicon dioxide nanocomposite were a commercial grade supplied by Cargill Dow LLC, Minneapolis, USA by extrusion method which were made of (PLA(with a specific gravity of 1.25 g/cm^3 (210 °C, 2.16 kg) and a melting temperature of 170 °C and the SiO_2 from Wacker-Chemie GmbH (Hydrophilic Wacker HDK® T40, with the density of 2.20 g/cm^3, BET surface area of 360–440 m^2/g).

Devices and methods

Consideration of polymer with scanning electron microscope (SEM)

At first, to prepare packaging cover samples, they are placed in laboratory falcons after provision of suspension in acetonitrile solvent (Merck German company), then 3 CC of the acquired solution are poured on the base with glue until the solvent evaporates, then it is transferred to spotter coater that has argon gas for consolidation of gilt coverage on available samples on the base. It should be noted that gold plating is used for increasing electrical guidance in samples that resulted image will be more obvious and existence of argon gas leads to creation of plasma (ionized particles). Therefore, electrons are separated from positive to negative pole based on created potential difference and absorbed by detector and transferred to monitor. After 10 minutes, prepared samples with gold coverage are transferred to box of microscope device. Finally, after configuration of SEM microscope on 10X zoom, sample images are displayed on the monitor that related images are presented in results section.

Mechanical features

Mechanical test of films is performed based on ASTM D 882 standard by using instron device, model 4465 made in USA. Films are cut in dumbbell shape with dimensions of 1.5×10 square centimeters and placed between two jaws. Primary distance between two jaws are 50 mm and loading speed 50mm/min. For each sample, 6 repetitions are executed. Length increase elongation at break, Young modulus and tensile strength of change of film shape and given force are recorded and calculated by software.

Consideration of chemical interaction of Furrier Transformation Infra-Red (FTIR)

The spectrum of FT-IR of films is recorded in limit of 400-400 Cm^{-1} with PERKIN ELMER 1650, spectrophotometer of FT-IR [5].

Statistical analysis

Used software for analysis of data is SPSS software pack and Excel spread sheet on Windows. Significant difference ($P<0.05$) are evaluated by using variance analysis (ANOVA). Moreover, Tukey test is used for confirmation of significant differences among averages.

RESULTS AND DISCUSSION

Scanning electron microscope images

Consideration of Silicon dioxide nanoparticles effect on morphological features of poly lactic acid film

SEM micrographs of poly lactic acid containing silica nanoparticles with weight percentages of 1%, 3% and 5% are presented in (Fig. 1). (Fig. 1 A) shows the level of pure PLA. In presented SEM micrographs in (Figs. 1B, C and D), nanoparticles are shown by white and spherical points. PLA surface (Fig. 1 A) is flat that is considered as a pure polymer. Proper and steady distribution of nanoparticles is observed for a sample with 1 weight percent of Silica weight. Proper dispersion and distribution of nanoparticles in polymer matrix that are key factors for improved materials can be related to special nature of nanoparticles of hydrophobic silica that causes lower interaction among particles. By increasing silica contents from 1-5 weight percent, nanoparticles start to from mass and homogenous silica in matrix reduces intensely according to silica contents with higher percentage. Moreover, more irregularity is observed in surface and cavities [6]. For silica of 5% weight, (Fig. 1D) shows distribution and non-uniform dispersion of silica nanoparticles with considerable number of masses.

Mechanical characteristics

Mechanical characteristics of films depend on intermolecular power of their constructive polymer chains, ratio of constructive combinations and additives that are added to the film and environmental conditions. Most important factors of measurement of mechanical features are resistance to tensile, elongation at break point, Young modulus etc [7-8].

Improvement of mechanical features of biodegradable films is important because of following aspects:

- High mechanical resistance of the film causes that it is not affected by mechanical damages of tension like perforation. Consequently, it can retain its deterrence feature against gases and moisture.
- High flexibility of film causes that it is correspond with shape of food material without break and it is used as cover easily.
- High mechanical resistance of film causes protection of food material from tensions during transportation.

In (Table 1), and (Figs. 1, 2 and 3), results of mechanical properties including resistance against tensile and young modulus or elastic modulus and elongation at break point in three levels of 1%, 3%

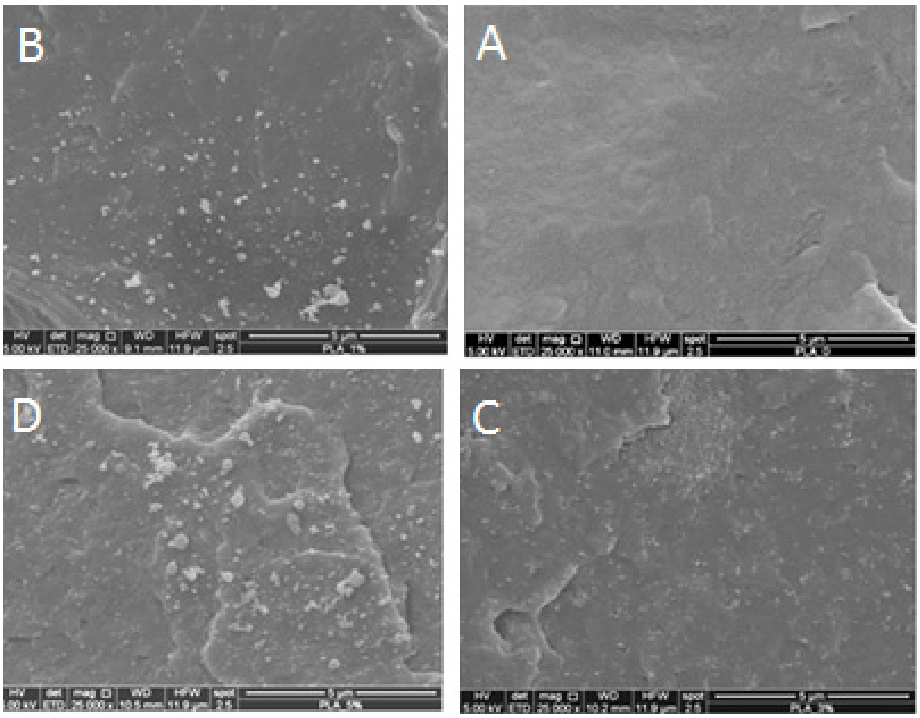

Fig. 1. Scanning electron microscopy images. A) PLA (25000x), B) PLA/$SiO_2$1% (25000x), C) PLA/$SiO_2$3% (25000x), D) PLA/$SiO_2$5% (25000x)

and 5% are considered. Moreover, average values for 8 samples are observed. Mechanical properties of provided nanocomposites are increased by adding 5 weight percent in comparison with pure PLA matrix. The reason for this result is steady connection of nanoparticles in PLA matrix.

The results indicated that by increasing nano-Si dioxide, tensile strength increased. High fragility is one of PLA features that should be improved for further applications. It was improved by adding nano-SiO_2 dioxide. (Fig. 1) shows that mechanical properties of tensile strength for poly lactic acid film is 29 that is minimum value and poly lactic acid film containing silicon dioxide 5% is 43 that is the maximum value. Moreover, tensile strength of poly lactic acid film containing silicon dioxide 1% is not significant [9-10].

As it is observed from (Fig. 2), elongation at break in pure poly lactic acid film is maximum with the value 17.5 and it is the minimum value of 10.5 for poly lactic acid film containing silicon dioxide 5%. Moreover, elongation at break of poly lactic acid film containing silicon dioxide 1% was not significant.

As it is observed from (Fig. 3 and 4), Young module is the minimum value of 2.3 for poly lactic acid film without silicon dioxide and it is maximum value of 3.1 for poly lactic acid film containing silicon dioxide 5%. Comparison of average of Young module of pure poly lactic acid film with poly lactic acid film

Table 1. Mechanical properties of poly lactic acid and its nanocomposite films

Sample	Tensilestrength (MPa)	Youngmodulus (GPa)	Elongation at break (%)
PLA	29	2.3	17.5
PLA/SiO_2%1	32	2.5	15
PLA/SiO_2%3	36	2.9	12
PLA/SiO_2%5	43	3.1	10.5

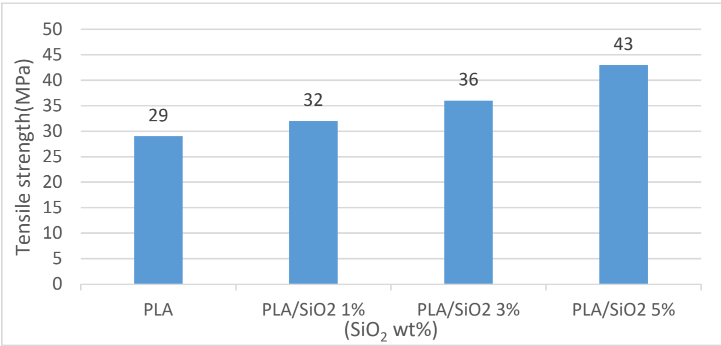

Fig. 2. Comparison of average of tensile strength for poly lactic acid films containing silicon dioxide

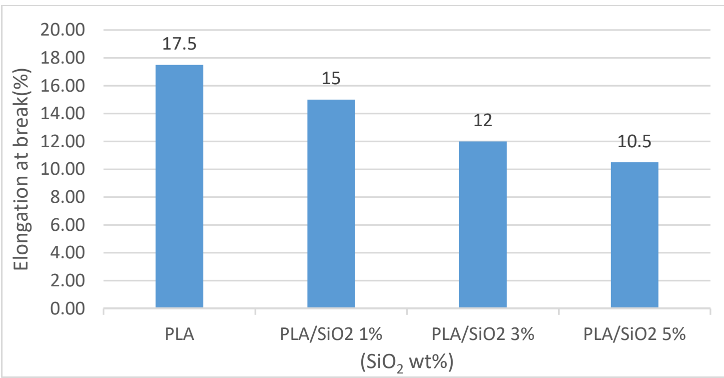

Fig. 3. Comparison of average of elongation at break for poly lactic acid films containing silicon dioxide nanoparticle

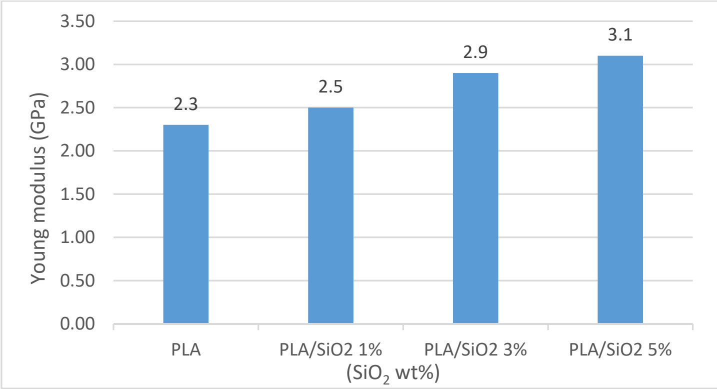

Fig. 4. Comparison of Young module for poly lactic acid films containing silicon dioxide nanoparticle

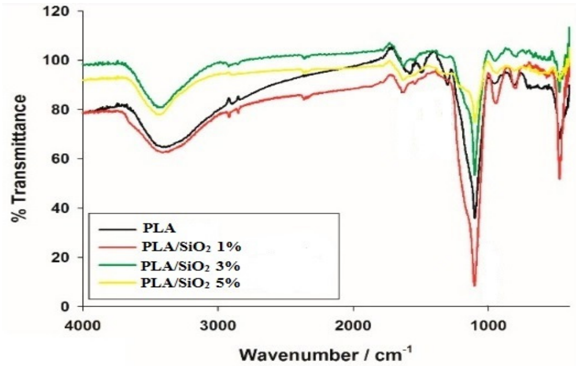

Fig. 5. FTIR spectrum for poly lactic acid film containing silicon dioxide nanoparticle

containing silicon dioxide 1% and poly lactic acid film 3% with poly lactic acid film containing silicon dioxide 5% were not significant.

Consideration of interaction of chemical materials (FTIR)

In this research, reaction between PLA/Sio_2 is studied by spectroscopy FTIR method. It is shown in (Fig. 5). FTIR spectrum for pure PLA in the chart shows absorption strings of features in limit 3500-3600 cm^{-1}- 2946-2999 cm^{-1} and 1757cm^{-1} that are caused by bending and stretching vibration of O-H, asymmetric stretching vibration of C-H and stretching vibration of C=O, respectively.

CONCLUSION

In morphological evaluation of SEM studies on PLA composite filaments, results show suitable and steady distribution of nanoparticles for the sample with 1 weight percent of silica. By increasing silica contents from 1-5 weight percent, nanoparticles started to form mass and homogeneous silica, based on silica contents with high percent, reduced intensely in matrix. Moreover, further irregularity is appeared in surface and cavities. Comparison of average of tensile strength of pure poly lactic acid containing silicon dioxide 1% means insignificance of average of these groups ($P>0.05$) while other percentages, in comparison with each other, show significance of average of tensile strength among groups ($P>0.05$). Moreover, comparison of average of elongation at break of pure poly lactic acid film with poly lactic acid film containing silicon dioxide 1% means insignificance of average of the groups ($P<0.05$) while other percentages, in comparison with each other, indicate significance of average of elongation at break among them ($P<0.05$). Comparison of average of Young module of pure poly lactic acid film with poly lactic acid film containing silicon dioxide 1% indicate significance of average of these groups. Moreover, comparison of poly lactic acid film containing silicon dioxide 3% with poly lactic acid film containing silicon dioxide 5 shows insignificance of average of two groups

($P<0.05$) while other groups show significance of average among them in comparison with each other ($P<0.05$).

In FTIR consideration, there is proper distribution of nano-SiO_2 dioxide in film composites and the connection if built and there isn't any difference with pure PLA.

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CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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