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Preparation of Polystyrene-Starch Composite by Melt Extrusion and Evaluation of its Mechanical, Thermal Biodegradation Properties

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ABSTRACT: In this work, composites of general-purpose polystyrene and corn starch with glycerol as a plasticizer were prepared in different ratios of starch and glycerol by melt mixing in the twin-screw extruder. The structure of prepared composites was studied using scanning electron microscopy analysis. Also, to evaluate the impact strength and thermal properties of composites, we used Izod impact strength test, melt flow index and Vicat softening temperature tests. Besides, to examine the interaction between composite elements, thermal stability, and degradation process, the samples were subjected to analysis using thermogravimetric analysis. Finally, to study the biodegradation properties, composite samples were buried in soil for 12 weeks and their weight changes were measured during two-week periods. Biodegradation results and scanning electron microscopy analysis showed that the rate of biodegradation not only starch present in composites but also depends on the quality of starch particle dispersion. Notched Izod test showed the independence of samples impact strength to starch present. Due to the reduction of stress accumulation points, homogeneous dispersion of starch in the matrix leads to increase impact strength in unnotched Izod test. Melt flow index test showed that addition of starch and glycerol leads to respectively increase and decrease in composites' viscosity.

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1. Introduction

There is a progressive demand for use of synthetic hydrocarbon polymers due to their lightness, flexibility, and ease of processing. Due to increased use of such polymers, there is an accumulation of non-biodegradable plastics leading to environmental pollution caused by disposed polyethylene and polystyrene materials. Therefore, many attempts have been made to replace synthetic polymers with cheap sources of biodegradable polymers such as starch, cellulose and its derivatives, etc. [1]. Polystyrene is one of the synthetic polymers with thermoplastic and non-degradable nature which is extensively used as packaging material [2]. Since the biodegradable polymers suffer from weak physical and mechanical properties, preparation of composite blends of polystyrene-starch in one hand can enhance its physico-mechanical properties, and on the other hand, induces a degree of biodegradability in the prepared composite material [3-5]. Thus, the purpose of this study was to develop a biodegradable grade of polystyrene aiming as a step to reduce the environmental pollution caused by disposal of such non-degradable polymeric substances. As a novelty of this research, biodegradable polystyrene-starch composites were developed by melt extrusion technique using an industrial scale extruder aiming to increase their biodegradability and to reduce the final production cost of synthetic plastics.

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2. Materials and Methods

Materials used to produce composite polymers were: General Purpose Polystyrene (GPPS), Pre-gelatinized corn starch, and glycerol as a plasticizer. Glycerol was used as a plasticizer due to having both hydrophilic and lipophilic ends, which attaches to starch and polystyrene molecules and induces matrix compatibility between two polymers. To produce composite polymers of starch-polystyrene the above material, at different ratios, were blended and fed to a co-rotating twin-screw melt extruder. Molten composite polymers were obtained as strips from extruder die and transferred to a cooling water batch followed by feeding to a granulating device to make polymer granules. Finally, packaging films were made from the obtained composite granules using melt extrusion. To study the biodegradation properties, samples were buried in soil for 12 weeks and their weight changes were measured during two-week intervals. Besides, the structure of prepared composites was studied using Scanning Electron Microscopy (SEM) analysis. To evaluate the impact strength and thermal properties of composites, Izod impact strength test, melt flow index and Vicat softening temperature tests were used. To evaluate interactions between composite elements, thermal stability and degradation process, the samples were subjected to thermogravimetric analysis.

3. Results and Discussion

Melt Flow Index (MFI) results for different composite

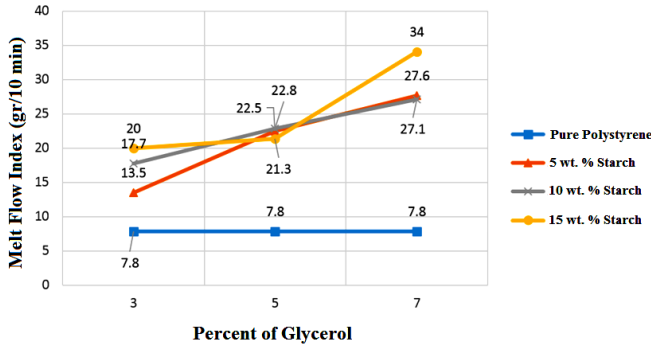

Fig. 1. Graph of melt flow index results by percent of glycerol in different starch percentages

polymer samples showed that, as expected, starch as hard and brittle filler decreased MFI values, whereas polystyrene as a plasticizer increased MFI. On other words, polymer melt viscosity was increased and decreased by starch and polystyrene, respectively. As shown in Fig. 1, by increasing the glycerol concentration MFI was increased. In all composite polymer samples, the effect of glycerol was dominant over starch effect. Thus, there was an increased MFI and reduced melt viscosity for all composite samples compared to those for pure polystyrene samples.

Vicat softening temperature analysis showed that incorporating starch into the composite polymer increased the Vicat softening temperature due to the high molecular weight and brittle nature of starch. On the other side, incorporating plasticizer substances such as glycerol reduced the Vicat softening temperature [6]. Notched Izod test results showed the incorporating starch reduced samples impact strength compared to that of pure polystyrene. However, by

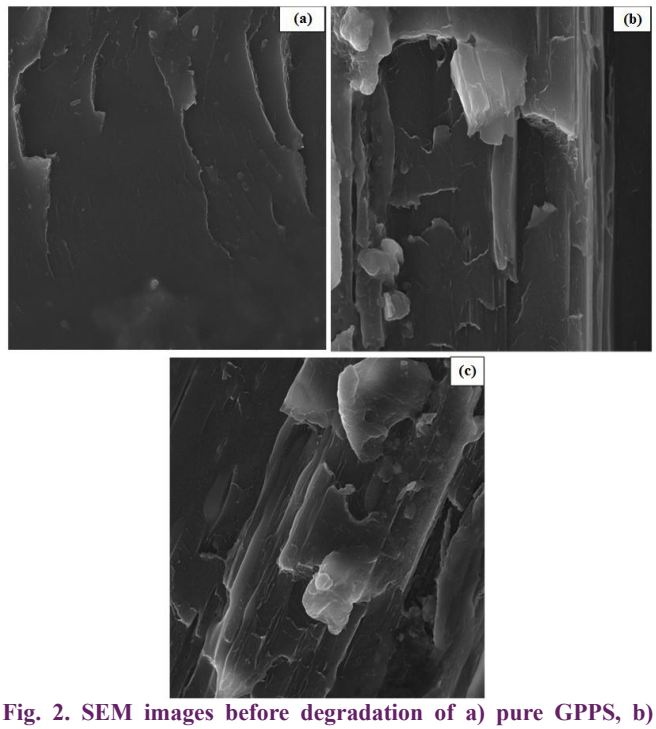

Fig. 2. SEM images before degradation of a) pure GPPS, b) GPPS-ST10-GL5 and c) GPPS-ST15-GL5 samples

incorporation of glycerol impact strength was decreased. Due to the reduction of stress accumulation points, homogeneous dispersion of starch in the matrix leads to increase in impact strength in unnotched Izod test. The results showed that composite films containing 5% glycerol had the highest impact strength values indicating a homogenous distribution and interaction between polystyrene, starch, and glycerol. From Fig. 2, SEM imaging showed that fracture surface morphology of pure polystyrene was very smooth and densely packed. However, by incorporating starch to polystyrene matrix, surface morphology of the composite films became coarse and heterogeneous. SEM images (Fig. 3) and biodegradation results from Soil Burial Test (SBT) of composite polymers after 30 days indicated the manifest of hollow voids due to starch destruction places in the composite polymer matrix.

As shown in Fig. 3, with increasing the destruction period, besides the appearance of these voids, the polystyrene matrix is also dissociated indicating a homogenous distribution of starch throughout the composite matrix which has been destructed. SBT results indicated that the rate of biodegradability was the highest in the first two weeks of soil burial period.

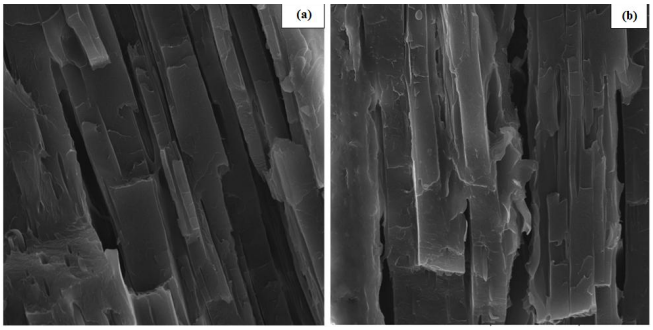

Fig. 3. SEM images after 30 days degradation in the soil of a) GPPS-ST15-GL5 and b) GPPS-ST10-GL5 composite samples

It was also shown that in Fig. 4, the weight loss of composite films was due to starch and glycerol destruction inside the polystyrene matrix [1, 7]. Weight loss and destruction rate were directly dependent on concentration of filler material i.e. starch and was inversely dependent on the quality of starch dispersion between the polystyrene polymeric matrix.

4. Conclusion

In this study, composite polymer of styrene and starch at different ratios with the presence of glycerol as plasticizer was produced using the melt extrusion method. Biodegradation test and SEM analysis showed that the rate of biodegradation directly depends on the concentration of starch present in the composites, and inversely depends on the quality of starch particles dispersion. It was shown that when starch is homogeneously dispersed in composite polymer matrix, its availability by destruction microorganisms becomes limited leading to lower rate of biodegradation. Notched Izod test showed the independence of samples impact strength to starch present. Due to the reduction of stress accumulation

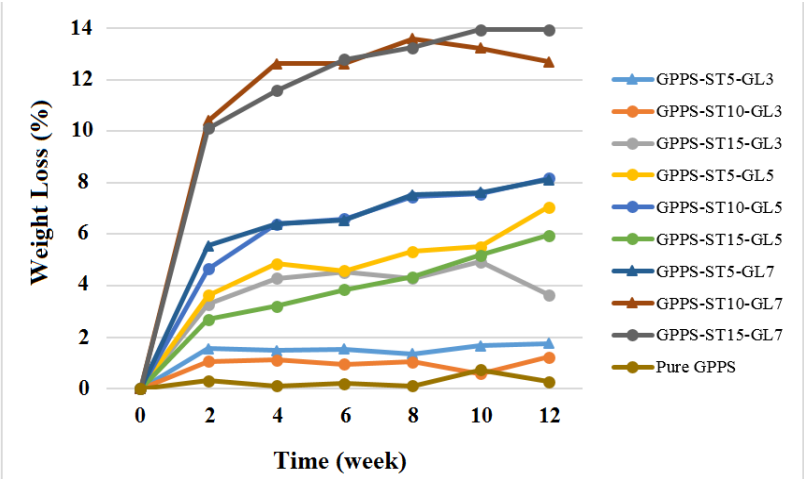

Fig. 4.Weight loss percent of all samples by time

points, homogeneous dispersion of starch in the matrix leads to increase impact strength in unnotched Izod test. MFI test results showed that incorporating starch and glycerol to styrene matrix led to an increase and a decrease in the melt viscosities of composites, respectively. Study of starch/glycerol ratio in the obtained results showed that when an optimal amount of plasticizer was used, better interaction between starch and polystyrene was achieved providing the best condition for the dispersion of starch particles in polystyrene matrix. The optimum ratio glycerol to starch was obtained to be 1 to 3. The ratio of filler material (starch and glycerol) to polystyrene should be in a situation that bioavailability of starch molecules to the degrading microorganisms is not lost.

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