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Mechanical and Thermal Properties of PLA/PBS Co-continuous Blends Adding Nucleating Agent

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Abstract

The influence of nucleating agents (nano-sized calcium carbonate and sodium benzoate) on mechanical and thermal properties of PLA/PBS co-continuous blends was investigated. PLA/PBS 60/40, 50/50, 40/60 wt% blends were compounded with NPCC or SB (0.5 and 1.0 phr) in a twin-screw extruder and fabricated into thin sheets by hot pressing. DSC was used to study glass transition temperature (T_g) and percentage of crystallinity (%X_c) of the blends. Morphology of fractured surface was examined using SEM. It is found that the PLA/PBS 50/50 wt% blend was co-continuous structure even incorporating NPCC or SB of 0.5 and 1.0 phr. Adding SB of 1.0 phr caused the PLA dispersed phases in the PLA/PBS 40/60 wt% to be smaller droplets distributed in the continuous PBS matrix. On the other hand, adding NPCC of 1.0 phr into PLA/PBS 60/40 wt% produced elongated continuous phase of PBS stripped out of PLA matrix. Adding SB into PLA reduced T_g from 63 to 60 ^oC, while NPCC nucleated higher %X_c of PLA phases in all blends. Tensile strength, elongation at break and energy at break of the blends were reduced when filled with NPCC and SB. This is due to increasing in crystallinity of the PLA phases and the presence of stress concentrators in the blends.

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Keyword: poly(lactic acid); poly(butylene succinate); co-continuous phase; nucleating agent

1. Introduction

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The blending of conventional polymers has been extensively employed to develop new polymeric materials. However, because of unfavorable enthalpy of mixing for two polymers, most polymer blends are immiscible and thus form phase-separated morphology: disperse domain structure in the matrix phase and co-continuous structure [1]. Such immiscible blends exhibit different types of heterogeneous morphology, which depend on the blend composition, interfacial tension, processing condition and rheological properties of the component.

When one component is present in the blend at a low concentration, a dispersed phase-matrix morphology is found, for which the shape of the dispersed particles can be spherical or fibrillar. As the concentration of the minor phase increases, particles become close enough and start to coalesce, reaching a point that corresponds to the percolation threshold point. Above this concentration, a greater and greater proportion of the minor component is incorporated into the percolation structure until at a certain volume fraction all the material of the blend components becomes part of a single percolating structure. This morphological structure is called *dual-phase continuity* or *co-continuity*, with each phase remaining continuously connected throughout the bulk of the blend. Co-continuous structures can be regarded as the coexistence of at least two continuous structures within the same volume. Blends with co-continuous structures may combine the properties of both components in a favorable way, for example, mechanical moduli [2].

Panyad and Hongsriphan [3] reported that when PLA content was up to 40 wt% in PBS/PLA blend, PLA dispersed phases were elongated and presented in uneven shapes. This resulted from the combination of low interfacial interaction between PLA and PBS and much higher viscosity of the PLA dispersed phases. When the PLA content was up to 50 wt%, the co-continuous morphology in polymer blend was formed. This co-continuous blend provided the highest tensile strength and elongation at break even though there was no compatibilizer modified the interfacial adhesion between phases.

Poly(lactic acid) (PLA) and poly(butylene succinate) (PBS) are known as biodegradable polyesters with good mechanical properties and degradability. Especially, PLA has been widely used in biomaterial applications because of its good biocompatibility and various physical properties. But its brittleness is a major defect for many applications, thus, studies on PLA blends with other polymers were carried out in order to modify various properties [4]. Bhatia*et al*. [5] blended PLA with PBS and reported that the blend was partial miscibility with the PLA/PBS blend of up to 80/20 wt% composition. PBS reduced the brittleness of PLA, thus making it a contender to replace plastics for packaging applications.However, tensile strength, modulus and percentage (%) elongation at break of the blends decreased with PBS content. Lui*et al.* [6] blended PLA with poly (ethylene/butylene succinate) (Bionolle) and found that adding Bionolle aided in crystallization of PLA. Bionolle concentration led to a slight increase in the strain-at-break of the blends but a decrease in the Young's modulus and ultimate tensile strength. Yokohara and Yamaguchi [7] studied the structure and properties of binary blends composed of poly (lactic acid) (PLA) and fibrous poly(butylene succinate) (PBS) and compared with those of blends having spherical particles of PBS in a continuous PLA phase. PBS particle, which showed nucleating ability for PLA, led to a high degree of crystallinity and enhanced the cold crystallization in the heat process.

In general, it is known that nucleating agents enhance the nuclei generation of semi-crystalline polymers in crystallization process and leads to the higher crystallization rate at higher temperature, resulting in increasing crystallinity. Thus, the utilization of nucleating agents improves physical and mechanical properties, processability, and productivity in mold processing [8]. Recently, nano-sized calcium carbonate ($CaCO_3$ or NPCC) has received a lot of attention because of its wide range of potential applications and its low cost. Various methods, such as high gravity reactive precipitation, have been developed to prepare NPCC particles with a narrow size distribution. Kim *et al.* [9] studied the effect of the $CaCO_3$ particles on the thermal stability of the PLA-based. They found that the tensile strength and modulus value of the composite were improved greatly without a significant loss in the elongation at break when the NPCC was incorporates up to 30 wt%. Sodium benzoate (SB) with fine particle sizes is