ABSTRACT

DESIGN OF BIOBASED AND BIODEGRADABLE – COMPOSTABLE ENGINEERED PLASTICS BASED ON POLY(LACTIDE)

By

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Poly(lactide) (PLA) is a biobased and biodegradable – compostable plastic that is derived from renewable resources such as corn and sugar cane. It possesses excellent strength and stiffness properties and is recognized as safe for biomedical and food packaging applications. Commercially, it costs ~$1/lb and is now competitive with the petroleum based polymers that have dominated the industry for decades. However, the material has some inherently weak properties that prevent it from certain applications – most notably, its rheological properties, brittleness, and poor high temperature performance. Cost effective modifications of the polymer to enhance these deficiencies could allow for increased applications and further commercial
growth. Multiple synthetic strategies have been developed to address PLA’s performance property deficiencies.

PLA typically exhibits poor melt strength and does not have the ability to strain harden, partially a result of its highly linear nature. Strain hardening and high melt strength are crucial elements of a material when producing blown films, a large untapped market for PLA. By increasing molecular weight and introducing long-chain branching into the material, these properties can be improved. Epoxy-functionalized PLA (EF-PLA) was synthesized by reacting PLA with a multifunctional epoxy polymer (MEP) using reactive extrusion processing (REX). These modified PLA polymers can function as a rheology modifier for PLA and a compatibilizer for blends with other biopolymesters. The modified PLA showed an increased melt strength and exhibited significant strain hardening, thus making it more suited for blown film applications. Blown films comprised of PLA and poly(butylene adipate-co-terephthalate) (PBAT) were produced using EF-PLA as a reactive modifier for rheological enhancement and compatibilization. This resulted in films with better processability (as seen by increased bubble stability) and improved mechanical properties, compared to a common rheology modifier used in industry. These modifiers have been successfully scaled up to a 400 kg/hr process and are currently used to make high quality biodegradable blown films for multiple commercial applications.

PLA is an extremely brittle material, typically experiencing only 3-4% elongation prior to fracture. This hinders some of its applications and therefore toughening is needed for future commercial growth. Two different methods of modifying PLA with polysiloxanes are studied and discussed. Polysiloxanes serve as a highly attractive material for toughening PLA due to
their inherent properties. Because of the longer bond and higher bond angle of the -Si-O-Si- (siloxane) backbone compared to a carbon based backbone, there is a reduced energy barrier for rotation leading to substantial flexibility. Polysiloxanes also possess good thermal and oxidative stability, biocompatibility, and very low surface tension values, all which could benefit PLA greatly.

Lastly, most injection molded PLA products lose their rigidity above $T_g$ ($\sim 55^\circ C$) due to a rubbery amorphous phase and low crystallinity. This prevents products like PLA cutlery from being used effectively at elevated temperatures, like those of hot foods. The high temperature mechanical properties of injection molded PLA are enhanced using a combination of nucleating agents and processing improvements to impart high levels of crystallinity, resulting in a substantial increase in the mechanical performance at these temperatures.

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