

# Poly(lactic acid): plasticization and properties of biodegradable multiphase systems

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Received 25 October 2000; received in revised form 1 January 2001; accepted 22 January 2001

## Abstract

Poly(lactic acid) (PLA) is a biodegradable aliphatic polyester well suited for disposable applications. PLA was plasticized with various biocompatible plasticizers. Their efficiency was evaluated in terms of glass transition temperature ( $T_g$ ) shift and mechanical properties improvement. Significant decrease in  $T_g$  and rise in the elongation at break was obtained with polyethylene glycol and oligomeric lactic acid. Furthermore, PLA was melt-blended with thermoplastic starch (TPS). The properties of subsequent TPS/PLA blends were investigated through tensile and impact testing, thermal analysis (DSC), dynamic mechanical analysis and microscopy (SEM). From the mechanical results, low level of compatibility was found. The blends showed two distinct  $T_g$ s. However, the PLA phase varied toward the  $T_g$  of TPS with the blend composition, indicating some degree of interaction. Microscopic observations revealed non-uniformly dispersed PLA inclusions in the TPS matrix, confirming that phase separation has occurred. © 2001 Elsevier Science Ltd. All rights reserved.

**Keywords:** Poly(lactic acid); Plasticizer; Thermoplastic starch

## 1. Introduction

Poly(lactic acid) (PLA) has received much attention in the research of alternative biodegradable polymers [1–3]. PLA is a linear aliphatic thermoplastic polyester, produced from renewable resources and readily biodegradable [4,5]. PLAs are produced by ring-opening polymerization of lactides and the lactic acid monomers used are obtained from the fermentation of sugar feed stocks [6]. Generally, commercial PLA grades are copolymers of poly(L-lactic acid) (PLLA) and poly(D,L-lactic acid) (PDLLA), which are produced from L-lactides and D,L-lactides, respectively. The ratio of L- to D,L-enantiomers is known to affect the properties of PLA, such as the melting temperature and degree of crystallinity. To date, PLA resins have mostly been used for biomedical applications such as drug delivery systems [7]. Thanks to mechanical properties comparable to those of polystyrene, PLA could reasonably substitute conventional polymers in domains such as packaging. However, the low deformation at break and quite elevated price of PLA limit its applications.

Considerable efforts have been made to improve the

properties of PLA so as to compete with low-cost and flexible commodity polymers. These attempts were carried out either by modifying PLA with biocompatible plasticizers, or by blending PLA with other polymers. Varying types of chemicals, such as citrate esters, have been tried to plasticize PLA [8]. Recently, plasticizers such as poly(ethylene glycol) (PEG), glucosemonoesters and partial fatty acid esters [9,10] were used to improve the flexibility and impact resistance of PLA. The resulting plasticized PLA materials gained in deformation and resilience. None of these studies proposed oligomeric lactic acid (OLA) and glycerol as plasticizers for PLA.

Blends of PLA with various non-biodegradable polymers have been investigated [11–13]. Biodegradable blends of PLA with other aliphatic polyesters such as poly( $\epsilon$ -caprolactone) [14–16], poly(butylene succinate) [17,18] and poly(hydroxy butyrate) [19,20] were also reported in the literature. Some of these blends were found to be immiscible, resulting in fairly poor mechanical properties. Surprisingly, none of these studies have investigated the use of thermoplastic starch (TPS) as the biodegradable blend component for PLA, although it offers unquestionable advantages in terms of cost and sustainability. TPS has been widely used in association with other polyesters because of its low cost, satisfactory properties, renewability and biodegradability. Blends of TPS with

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