Iranian Polymer Journal (2019) 28:403–415
https://doi.org/10.1007/s13726-019-00709-3

ORIGINAL RESEARCH

Thermal and biodegradation properties of poly(lactic acid)/rice straw composites: effects of modified pulping products

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Received: 13 November 2018 / Accepted: 8 April 2019 / Published online: 15 April 2019

Abstract

In this work, rice straw (RS) as an abundant biomass was chemically thermoplasticized through alkali pulping and benzylation reactions, which destroy inter- and intra-molecular hydrogen bonding of the lignocellulosic constituents and dissociate the cellulosic component of RS from lignin. Two different products of RS benzylation process including benzylated pulp (BP) and pulping liquor (BL) rich in cellulose, with the former, and lignin, with the latter, were incorporated into poly(lactic acid) (PLA) using a twin-screw extruder. By substituting the hydroxyl groups of the lignocellulosic constituents with non-polar benzyl groups, the filler/PLA interfacial adhesion was improved considerably in which no evidence of debonding was observed on cryofractured surfaces of the PLA/BL composites. Indoor soil biodegradation test was performed on samples for 128 days and their weight loss, water uptake, visual observations and crystallization were investigated. While PLA sheets showed negligible deterioration and roughly kept their whole weight, the PLA biocomposites demonstrated considerable degradation after soil burial test due to the higher water absorption, lower glass transition temperature and larger biodegradation rate of fillers. The modified pulping products of RS showed a higher thermal stability than their thermoset-like predecessors. The non-isothermal DSC results demonstrated that the addition of BP and BL particles to PLA reduced the glass transition and melting temperatures of the matrix and resulted in higher degree of crystallinity. The findings showed that RS pulping and benzylation reactions successfully led to more effective fillers for PLA than rice straw.

Keywords Poly(lactic acid) · Rice straw · Biodegradation · Thermal stability · Thermoplasticization

Introduction

One of the severe environmental concerns, especially in the recent decade, is the plastic waste that remains after utilizing petroleum-based polymers. The plastic waste as a critical pollutant in soil and water causes non-renewable fossil fuel depletion and landfill capacity reduction due to their considerable annual consumption and non-biodegradable nature [1, 2]. As a direct result, researchers have focused on novel sustainable polymers that are synthesized from renewable resources and susceptible to biodegradation process in the ecosystems [3]. One of these polymers is poly(lactic acid) (PLA), an aliphatic polyester derived from starch, that is of great interest owing to favorable properties such as good processability and mechanical performance, hyrophobicity and barrier properties, accessibility, non-toxicity, biocompatibility and biodegradability [3]. However, PLA has some drawbacks that limit its marketability such as high cost, low toughness and inherent brittleness [2, 4]. Although, PLA has been verified to be a naturally degradable plastic in soil or compost, it is shown to be less susceptible to microbial attack and degradation in a natural environment than other biodegradable polymers such as starch and poly(ε-caprolactone) [5]. The slow biodegradation process can be explained by the glass transition temperature (T_g) of PLA that is higher than ambient temperatures and scarce PLA-degrading microorganisms in the environment [6, 7]. Karamanlioglu and Robson in 2013 investigated the biotic and abiotic influential factors on PLA degradation rate in soil and compost and showed the significant disintegration and weight loss of PLA coupons buried at temperatures close to the T_g of PLA as well as substantially their greater degradation rate in compost rather than sterile compost extract [3].

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