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ORIGINAL RESEARCH

Polylactic acid nanocomposites toughened with nanofibrillated cellulose: microstructure, thermal, and mechanical properties

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Abstract

Structure–property interdependency is of vital importance in developing advanced polymer nanocomposites as well as enhancing their ultimate properties. In this research study, toughening of polylactic acid (PLA) with nanofibrillated cellulose (NFC) was studied and comparison was made between the thermal and mechanical properties of systems containing pristine and modified NFC. NFC was modified through two different methods: acetylation of hydroxyl groups and grafting of poly(ethylene glycol) (PEG) onto cellulose chains. Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), and differential scanning calorimetry were employed to probe into the surface characteristics, thermal properties, and crystallinity of NFC/modified NFC, respectively; moreover, SEM imaging was utilized for surface morphology of the samples. Subsequently, PLA with modified and unmodified NFC was prepared to evaluate the filler addition effect on toughness. Acetylated NFC has changed the PLA crystallinity degree and rate, which affected the modulus of PLA, as signaled by the changed NFC surface. Particularly, mechanical and toughening behaviors of the prepared nanocomposites were analyzed based on tensile measurements which showed an eightfold rise in toughening along with 18% decrease in modulus of the samples comprising 1 wt% of acetylated NFC compared to a blank PLA. However, a sevenfold increase in toughening was observed upon introduction of both modified NFC to the PLA matrix. SEM observations divulged proper dispersion of NFC-*g*-AC in the PLA matrix which reduced stress concentration, but enhanced toughness in comparison with NFC-*g*-PEG with agglomeration that caused stress concentration leading to brittle behavior. In the light of the obtained results, it can be inferred that brittle PLA can be toughened by the surface-modified NFC. This research study can illuminate the way for future works on the modifications of nano-scale fillers/additives to achieve improved mechanical and thermal properties of PLA.

Keyword Polylactic acid · Cellulose · Toughness · Nanofibers · Biopolymers · Crystallization

Introduction

Polylactic acid (PLA), as a linear aliphatic thermoplastic with ecofriendly features, has received a great deal of attention owing to its multifaceted beneficial aspects such as biocompatibility, biodegradability, and non-toxicity, and, thus, has been applied in a wide range of applications such as packaging and biomedical industry [1–3]. However, inappropriate mechanical properties of PLA-like toughness limit its usage in various applications [4, 5]. Considerable efforts have been made to find feasible routes to overcome above-mentioned concerns, among which are blending with other polymers [6–8], optimization of crystallization process [9, 10], and the incorporation of additives [11, 12]. Toughness is a challenging issue in PLA properties and chemical modification is the appropriate way to achieve the though PLA [13]. PLA nanocomposites have attracted a significant attention because of their unique properties [14, 15]. Singh et al. [16] reported that mechanical properties of PLA can be improved by the incorporation of modified multi-walled carbon nanotubes (CNTs) under a critical concentration well below CNTs' bundling level along with enhancing the biocompatibility.

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