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ORIGINAL PAPER

Effect of flax fiber content on polylactic acid (PLA) crystallization in PLA/flax fiber composites

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Abstract Crystallization of polylactic acid (PLA) has a profound effect on its thermal stability and mechanical properties. However, almost no crystallization occurs in actual injection molding process due to rapid cooling program. In this paper, flax fiber was employed as nucleator to enhance the crystallization capability of PLA. Effects of flax fiber content on cold crystallization, melt crystallization, crystallinity, crystal form, morphologies, and size of spherulites of PLA/flax fiber composites were investigated. Dynamic mechanical analysis was innovatively employed to study cold crystallization temperature of PLA/flax fiber composites under dynamic force, and the relationship between cold crystallization temperature (y) and flax fiber content (x) data was fitted by the function $y = 34.1 \times \exp(-x/5.7) + 78.0$. The differential scanning calorimetry results showed that the cold crystallization temperature of composites dropped, the melt crystallization temperature of composites increased, and the crystallinity of composites improved with increasing of flax fiber content. Using polarized optical microscopy, it has been found that the spherocrystal size of composites was much smaller than that of neat PLA, and flax fiber induced transcrystallization on the flax fiber surfaces. Wide-angle X-ray diffraction was applied to reveal that flax fiber significantly enhanced the formation of α-form PLA crystals.

Keywords Polymer composites · Polylactic acid · Flax fiber · Nucleator · Crystallization

Introduction

Polylactic acid (PLA), a biobased and biodegradable thermoplastic, has received considerable attention over the past few decades for its excellent mechanical properties and relatively low-cost production [1]. PLA is a polymer with a regular chain structure that is, therefore, able to crystallize under suitable conditions. Due to its relatively rigid chain, PLA crystallizes very slowly [2], and special processing conditions (long annealing time) are needed to ensure maximized mechanical properties. The failure to observe such conditions leads to very low crystalline content, poor mechanical and thermal properties and, consequently, low Vicat softening point. To accelerate the crystallization and improve crystallinity of PLA, numerous strategies have been employed, for instance, by blending, copolymerization and manipulation of the processing.

Incorporation of a nucleating agent into a PLA matrix is the most effective method to increase the nucleation density and to shorten the nucleation time of PLA. The nucleating agent acts as a heterophase within the PLA matrix, providing nuclei for crystallization [3, 4]. The dose of nucleating agent determines not only the crystallinity, but also the number, size and integrity of PLA spherulites. Moreover, the type of nucleating agent may have profound influence on the properties of PLA. As inorganic particles, carbon nanotube [5], calcium sulfate [6], clay and talc [7] are incompatible with PLA, they lead to relatively low mechanical properties. By contrast, organic compounds are favorable nucleating agents for promoting PLA crystallization due to their high solubility with PLA. *N,N′*-Bis(benzoyl) suberic acid dihydrazide

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