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The effect of talc orientation and transcrystallization on mechanical properties and thermal stability of the polypropylene/talc composites

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ABSTRACT

The isotactic polypropylene/talc composites with talc stratified distribution were prepared by a multilayered co-extrusion technology. The talc orientation in polypropylene matrix was studied by scanning electronic microscopy and polarized light microscopy. The crystallization behavior of the composites was investigated by differential scanning calorimeter and polarized light microscopy. The mechanical properties and thermal stability of the composites were compared with the conventional blends by tensile machine and thermogravimetric analyzer, respectively. The composites with talc stratified distribution exhibited better mechanical properties and thermal stability than that of the conventional blends, which were related to the transcrystals in the unfilled polypropylene layers and the high orientation of talc particles in the filled polypropylene layers.

1. Introduction

Isotactic polypropylene (iPP) which is one of the most important commodity polymers exhibits excellent mechanical properties, attractive chemical resistance as well as low cost and can be reprocessed several times without significant loss of its properties. These properties can be further tailored with copolymerization, rubber modification, and inorganic reinforcement [1–9]. Materials based on iPP are widely used in automobile, electronic appliances, household appliances and construction industries. The filled iPP materials have attracted considerable attention owing to their unique mechanical, thermal, optical, electric and magnetic properties resulting from the synergistic effect between the filler and the matrix. Inorganic particles such as talc, glass fiber, calcium carbonate, mica, titanium dioxide and clay normally used as fillers to improve properties of the composites [4–9].

For many applications, the properties of filled polymer materials are obviously dependent on the filler amount but above all, they are very linked to the distribution and orientation in the matrix [10,11]. Taking recent science's papers as an example, the well-dispersed large volume fractions filled polymer nanocomposites were successfully prepared by a process of layer-by-layer assembly. The homogeneous materials with planar orientation of the nanosheets exhibited ultrastrong and stiff properties [12,13].

Talc is one of the most common filler to reinforce iPP because of its low cost and high aspect ratio. The final properties of talc filled iPP composites are dependent on the inherent characteristics of talc, their orientation and the varying crystal morphology of the matrix. It was reported that talc could enhance the mechanical properties [14,15], dimensional stability [16,17] and heat-deflection temperatures [18–20] of the iPP resins. In talc-filled iPP composites, the presence of this platelike filler acting as a heterogeneous nucleating agent could greatly modify the crystal morphology of the iPP matrix [21]. The final properties of talc filled iPP are related to the crystal morphology and the distribution of talc particles [22–26]. The epitaxial crystals were observed at the interfaces between the fillers and matrix [22,23]. The crystals oriented perpendicular to the talc surface and therefore could be tuned by the talc orientation [24,25]. The formation of the network between talc particles and crystalline lamella was very important to the properties of PP/talc composites [26].

Transcrystal which is one kind of epitaxial crystal is a well-known crystalline feature in polymers, which occur as the result of overgrowth of the polymer crystals on the organic and inorganic fibers [27]. The transcrystals give stiff and brittle in comparison with the fine spherulites, which probably enhance the Young's modulus, adhesion and shear strength of the iPP matrix [28–31]. In our previous study, the transcrystallization could be tuned by controlling the distribution of Calcium carbonate ($CaCO_3$) fillers, i.e. the stratified distribution, and then enhanced the mechanical properties of the composites [32]. The work of the iPP/$CaCO_3$ composites was focus on the filler content effect on the transcrystals. Here, we focus on the effect of the layer numbers on the transcrystals and talc orientation of the iPP/talc composites with talc stratified distribution.

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Recently, a kind of multilayered co-extrusion technology was employed to prepare the multilayered composites with alternating polymer A and B layers for improving the mechanical [33], electric [34], barrier [35,36] and crystallization [37–39] properties. In this work, the layer-multiplying coextrusion which was developed in our lab was used to prepare the iPP/talc composites with talc stratified distribution, i.e. talc-filled PP layers alternating with unfilled PP layers. The transcrystallization and talc orientation of the composites was investigated with the focus on the understanding of the improvement of the mechanical properties and thermal stability. The effect of layer thickness on transcrystalline morphology of the composites was investigated to control the crystalline morphology of iPP/talc composites and then further enhance the mechanical properties.

Table 1
The code, the average thickness of the iPP layers and the iPP/talc layers of the samples.

Sample code	Description	$t_{iPP/talc,\ Average}$/μm	$t_{iPP,\ Average}$/μm
iPP-5	Conventional blends with 5 wt% talc	1000	0
iPP-10	Conventional blends with 10 wt% talc	1000	0
2-Layer iPP/iPP-10	2-layer, the iPP/talc layers with 10 wt% talc	500 ± 50	500 ± 50
4-Layer iPP/iPP-10	4-layer, the iPP/talc layers with 10 wt% talc	250 ± 10	250 ± 10
16-Layer iPP/iPP-10	16-layer, the iPP/talc layers with 10 wt% talc	60 ± 10	60 ± 10
64-Layer iPP/iPP-10	64-layer, the iPP/talc layers with 10 wt% talc	15 ± 5	15 ± 5

2. Experimental

2.1. Materials

A commercially available isotactic polypropylene (iPP) was manufactured by Lanzhou Petroleum Chemical Incorporation (Gansu, China), with a melt flow index of 2.5 g/10 min (190 °C, 2.16 kg) and a density of 0.90–0.91 g/cm^3. The talc particles with an average particle size of 13 μm and an average aspect ratio of 40:1 were produced in Guangxi Longguang talc company (Guangxi, China). The talc was dried for 12 h at 80 °C in a vacuum oven before extruding.

2.2. Sample preparation

Firstly, the iPP/talc pellets containing 0, 5.0 and 10.0 wt% of talc were prepared by melt processing. The talc powder carefully compounded by hand with PP pellet and then melt-mixed in a twin-screw extruder at 200 °C and 30 rpm. The obtained molten filaments were cooled, pelletized and dried to obtain the iPP/talc pellets. Secondly, the iPP/talc composites with talc stratified distribution were prepared by feeding the pure iPP in *Extruder A* and the iPP/talc pellets in *Extruder B*, coextruding into the feedblock to form two layers and then doubling layers from the layer-multiplying elements (LMEs) at 200 °C. The schematic diagrams for the multilayered coextrusions and LMEs have been shown in Fig. 1a. In the LME, the polymer melt is divided, multiplied and finally recombined, as shown in Fig. 1b. It is obviously a kind of fish-tail flow. It was reported that the flowing behavior in fish-tail duct could be regarded as the combination of extending flow and convergent flow which would make the shear stress be high in the flowing duct [40].

As a result, an assembly of n LMEs can produce a lamellar composite with 2^{n+1} layers. The 2-, 4-, 16- and 64-layer iPP/talc composites were prepared by adding 0, 1, 3 and 5 LMEs, respectively. The processing condition (temperature, extrusion rate, cooling speed, drawing speed, etc.) were set constant among the samples with different layer number to facilitate the evaluation of the results. The thickness of all the samples with different number of layers was controlled by the exit die and the cooling

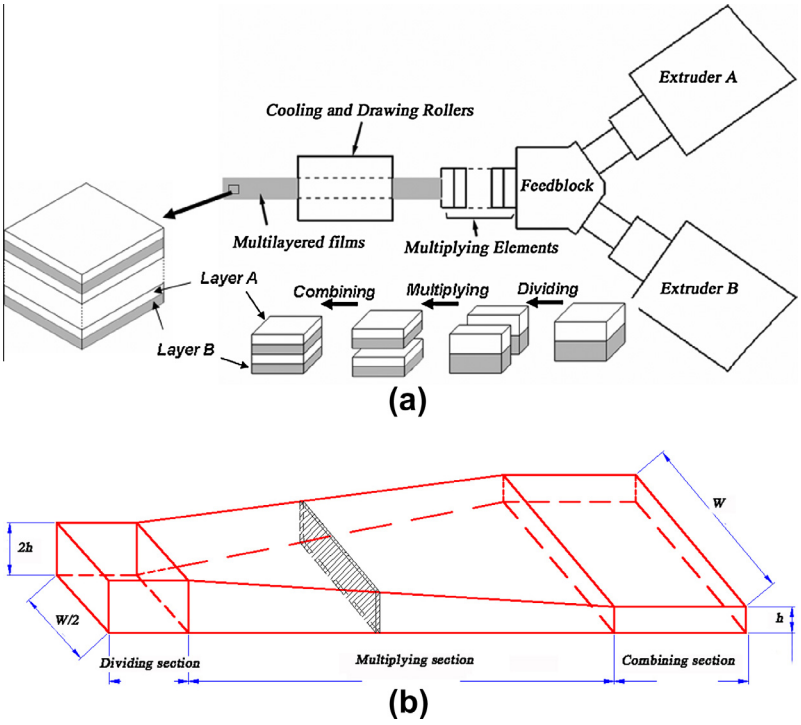

Fig. 1. Schematic draw of the setup of the layer-multiplying coextrusion (a) and half of the flow geometry in the LME (b). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)