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Time evolution of phase structure and corresponding mechanical properties of iPP/PEOc blends in the late-stage phase separation and crystallization

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Abstract

A typical toughened polymeric alloy system, isotactic polypropylene (iPP)/poly(ethylene-*co*-octene) (PEOc) blend, was selected in this study to investigate the influence of phase separation and crystallization on the final mechanical properties of the polyolefin blend. The time dependence of the morphology evolution of this iPP/PEOc blend with different compositions was annealed at both 200 and 170 °C and investigated with scanning electron microscopy (SEM) and phase contrast optical microscopy (PCOM). It was found that under the above two phase separation temperatures, the domain size of iPP80/PEOc-20 (PEOc-20) increases only slightly, while the structure evolution of iPP60/PEOc-40 (PEOc-40) is quite prominent. The tensile tests revealed that the mechanical properties of PEOc-20, including break strength and elongation at break decrease only in a very small amount, while those of PEOc-40 are depressed obviously with phase separation time. The decrease of interphase and a sharper boundary resulting from domain coarsening during the late-stage phase separation are responsible for the poor tensile properties. It is believed that the composition, the annealing time and the processing temperatures all contribute to the morphology evolution and the consequent mechanical properties of iPP/PEOc blends, furthermore, the crystallization procedure is another crucial factor influencing the ultimate mechanical properties of the investigated blends.

Keywords: Polypropylene/poly(ethylene-*co*-octene) blend; Morphology evolution; Mechanical property

1. Introduction

Isotactic polypropylene (iPP) satisfies a wide range of applications owing to its excellent properties such as chemical resistance, electrical resistance, low density, relatively low cost, and so on. However, its poor impact properties, especially at low temperature, limit its extensive use in industries [1–5]. In 1990s, the copolymers of ethylene and α-olefin became available in vast amount based on the development of Dow's INSITE™ constrained geometry catalyst technology (CGCT), which resulted in the possibility of the control of molecular weight, molecular weight distribution and comonomer distribution in polymerization of new copolymers [6,7]. The commonly used polyolefin elastomers are classified according to the types of comonomers as poly(ethylene-*co*-butene) (PEB), poly(ethylene-*co*-hexene) (PEH) and poly(ethylene-*co*-octene) (PEOc), among which PEOc is known as the most often used one owing to its excellent elasticity originating from the comparatively long side chains. Therefore, PEOc has been used as a polyolefin elastomer to toughen iPP and other species of polyolefins and it shows good dispersion in

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iPP due to the lower interfacial tension compared with ethylene–propylene rubber (EPR) and ethylene–propylene–diene rubber (EPDM) [3,5,8–10]. As a result, PEOc has been considered as a better iPP impact modifier and is gradually substituting EPR and EPDM. Therefore, iPP/PEOc blend system has been attracting more and more interests now. The rheological properties, phase morphology, crystallization behavior, mechanical and thermal properties of iPP/PEOc blends have been investigated extensively from both commercial and academic point of view [1–4,8–11]. Very recently, the addition of inorganic component to iPP/PEOc blends as a third component has aroused another hot trend [12,13], and shear-induced crystallization in iPP/PEOc blend has also been reported [14]. Among all these iPP/PEOc blend systems, the melt miscibility and the correlation between phase behavior and mechanical properties have been seldom reported.

The melt miscibility of polyolefin blends has been studied comprehensively by virtue of light scattering [15,16], small angle neutron scattering [17], confocal laser scanning microscope [18,19], optical microscope [20,21], and so on. Furthermore, the time dependence of morphology evolution of binary blends quenched from homogeneity to immiscibility has attracted much attention to elucidate the phase separation based on spinodal decomposition (SD) [16,18,19] or nucleation-growth (NG) mechanism [19,22,23]. If the binary blend is quenched into unstable region, phase separation will occur through SD, while for shallower quenches into metastable region, the NG will happen. Hashimoto et al. carried out a series of research work on the kinetics of SD in polymer blends [15,16,24]. Very recently, Han et al. reported the fluctuation-assisted crystallization in PEH/PEB blend system [25,26]. However, it is difficult to investigate the miscibility of iPP/PEOc blend in the molten state, due to the very close refractive indices of the two components, which are incapable of illuminating the observed "homogeneous state" as really miscible or not. That is the same case as iPP/EPR blends previously reported [17]. So, up to now there has been no report of a complete phase diagram for iPP/PEOc blend. Yao [27] investigated the phase diagram of this system, and just the compositions close to the two ends were experimentally traced out, while the in-between part was needed to be simulated resulting from the closeness of the refractive indices of the two components in quite a broad temperature range need to be simulated. According to Yao's study, the phase diagram of the iPP/PEOc blend system should obey the behavior of upper critical solution temperature (UCST).

In this paper, the time evolution of phase structure and the corresponding mechanical properties of iPP/PEOc blends with different compositions are concerned in terms of morphology development with phase separation proceeding. The effect of phase separation on mechanical properties of this system has been seldom reported, though it is of great significance in practical material processing. It should be pointed out that due to the aforesaid difficulties, the blends did not undergo a homogeneous state firstly and then a temperature drop to phase separation region, but directly annealed at a heterogeneous state to give rise to morphology evolution. It is noted that the details of phase separation kinetics are beyond the scope of the present research.

2. Experimental

2.1. Materials and blending

Isotactic polypropylene (iPP1300) with $M_w = 4.1 \times 10^5$ and $M_w/M_n \sim 4$ was supplied by Beijing Yanshan Petrochemical Co. Ltd. A metallocene catalyzed copolymer of ethylene and 1-octene (PEOc, Engage 8150) with $M_w = 1.5 \times 10^5$, $M_w/M_n \sim 2$ and 30.6 wt% of comonomer was obtained from DuPont–Dow Elastomers. The molecular weight and molecular weight distribution were obtained from gel permeation chromatography (GPC). The comonomer content was calculated according to ^{13}C NMR spectra.

The blends of PEOc-20 and PEOc-40 containing PEOc weight percent of 20 and 40, respectively, were prepared using a co-rotating twin screw extruder (TSE-30A) with an aspect ratio of $L/D = 40$. The temperatures from feed to die zones were 180, 190, 200, 220, 220, 220, 220, 200, 190 and 180 °C. The screw speed was set at 100 rpm. The blending was performed twice to ensure a better dispersed morphology.

2.2. Morphology investigation

2.2.1. Phase contrast optical microscopy

Phase contrast optical microscopic (PCOM) observations were carried out using a BX51 Olympus optical microscope equipped with a C-5050zoom Olympus camera. The temperature was monitored with an LTS350 Linkam hot stage. The films with a thickness of ca. 60 μm were prepared by using a home-made compression molder.

The experimental process consistent with the mechanical sample preparation procedures is depicted as follows. PEOc-20 and PEOc-40 blends were directly annealed at 200 °C or cooling from 200 to 170 °C and then annealed at 170 °C. During the annealing process at 200 or 170 °C, the phase contrast micrographs were taken as the morphology evolved. The whole processes of the treatment were under nitrogen protection.

2.2.2. Scanning electron microscopy

A JSM-6700F JEOL scanning electron microscope (SEM) operated at 5 kV was applied to examine the phase evolution morphology of tensile bars of iPP/PEOc blends. The crosssection of the undeformed samples was cryogenically fractured in liquid nitrogen and etched with *n*-heptane to remove the PEOc phase from the iPP matrix. The deposition of a platinum layer on the fractured surface was performed prior to SEM observations.

2.3. DSC measurement

The crystallization behavior of the PEOc-40 was carried out on a Perkin–Elmer differential scanning calorimeter

(DSC7). The heating scans were performed in the temperature range from 0 to 200 °C at a heating rate of 10 °C/min under nitrogen atmosphere with the sample weight of about 2−4 mg. Melting temperatures and fusion enthalpies were determined from the heating runs to estimate the perfection of the crystals. The instrument was calibrated by the standard material, indium.

2.4. Tensile test

2.4.1. Sample preparation

The tensile test samples were prepared through three different processes described below.

Annealing at 200 °C (Fig. 1a). The pellets of PEOc-20 and PEOc-40 were preheated at 200 °C on an LP-S-50 compression molder for 5 min (denoted as t_h), pressed under the pressure of 5 MPa at 200 °C for 2, 10, 30, 60 and 150 min (t_a or t_p), respectively, and then cooled down to 35 °C at a cooling rate of 15 °C/min and kept for 5 min.

Annealing at 170 °C (Fig. 1b). The pellets of PEOc-20 and PEOc-40 were preheated at 200 °C on an LP-S-50 compression molder for 5 min (t_h), pressed under the pressure of 5 MPa at 200 °C for 2 min (t_p), and then cooled down to 170 °C at a cooling rate of 15 °C/min, followed by annealing at 170 °C with pressure for 2, 10, 30, 60 and 100 min (t_a), respectively. After each annealing procedure at 170 °C, the samples were quickly transferred to a TDM-50-2 compression molder with the temperature set at 35 °C and pressure at 5 MPa for 5 min. It should be noted here that the procedures following the annealing steps at 200 and 170 °C are different and is limited by experimental conditions, for the LP-S-50 compression molder can only provide one cooling step.

Annealing at 170 °C followed by isothermally crystallizing at 130 °C (Fig. 1c). After each annealing procedure at 170 °C for 2, 30, and 100 min (t_a), respectively, the samples were quickly transferred to a TDM-50-2 compression molder (130 °C) to undergo an isothermal crystallization for 60 min (t_c) under the pressure of 5 MPa, followed by quick transferring to a TDM-50-2 compression molder with the temperature set at 35 °C and pressure at 5 MPa for 5 min.

2.4.2. Tensile test

The tensile bars were cut out according to GB13022-9 with a RP/PCP pneumatic serving machine from the iPP/PEOc sheets prepared by the above-described processes, and then held in an LRH-250A cultivation cabinet of constant temperature (23 °C) and humidity (50%) for 48 h before testing. The tensile bars were dumbbell-shaped with the length of 25 mm, width of 6 mm, and thickness of 1 mm.

The tensile experiments were performed on an Instron 3365 universal mechanical testing machine at room temperature with a crosshead speed of 50 mm/min. The testing results presented were the average of five samples.

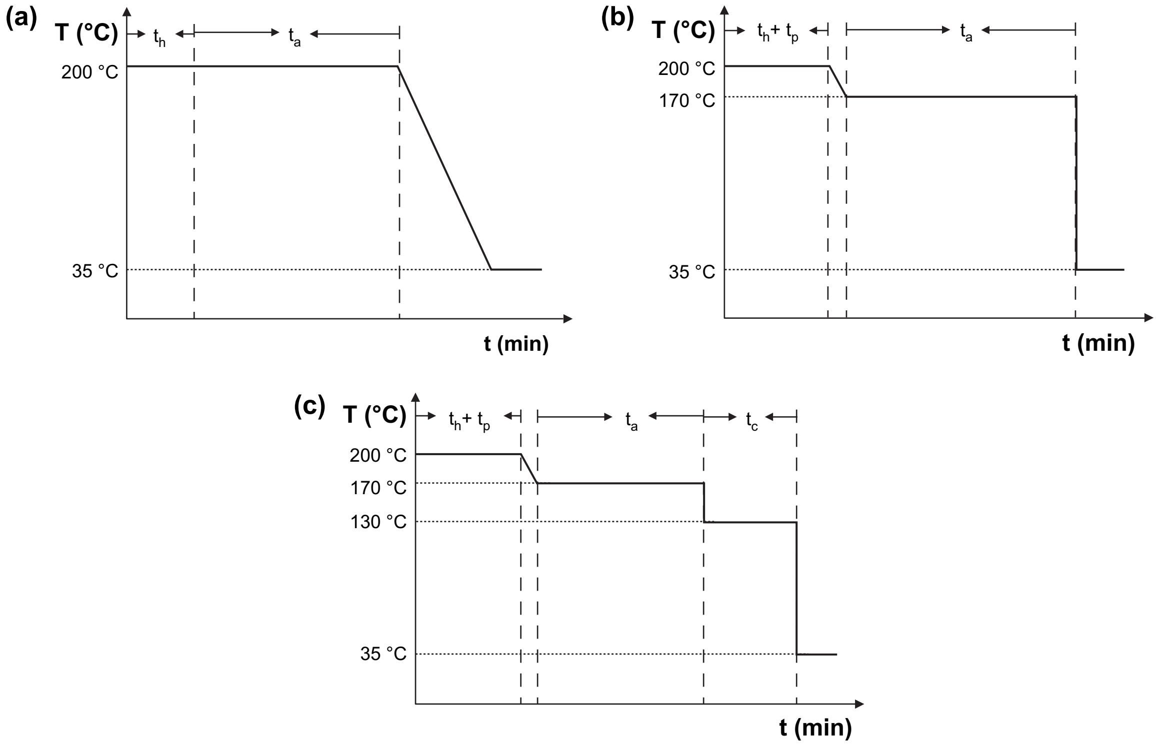

Fig. 1. Schematic illustration of sample preparation processes: (a) annealing at 200 °C for different times; (b) annealing at 170 °C for different times; (c) annealing at 170 °C for different times and then isothermally crystallizing at 130 °C for 60 min. All the samples were at last kept at 35 °C. Here, t_h, t_p, t_a and t_c denote preheating time, pressing time, annealing time and crystallization time, respectively.

3. Results and discussion

3.1. Phase separation and morphology development of iPP/PEOc blends

3.1.1. Phase contrast optical microscopy

The phase contrast optical micrographs of PEOc-20 and PEOc-40 annealing at 200 and 170 °C are all shown in Fig. 2. The optical microscope employed here provided direct observation of real space phase morphology development. In the images, the dark domains indicate PEOc-rich phase, while the white domains iPP-rich phase.

For both samples of PEOc-20 and PEOc-40, the heterogeneous structure was observed at the beginning of the experiments. In Fig. 2, the bicontinuous interconnected structure was visible for both samples annealed for 7 min at 200 °C and 2 min at 170 °C. The bicontinuous interconnected structure is the typical characteristic of spinodal decomposition [19,26], indicating that the phase separation of PEOc-20 and PEOc-40 at both 200 and 170 °C follows SD mechanism. The characteristic length increases due to the concentration fluctuation as the phase separation proceeds in time scale, accompanied with the decreasing of the interphase and the sharpening of boundaries. All these variations are thermodynamically predominated. The coarsening [17,19,23,28,29] of phase domain gets more and more obvious with the increase of annealing time at both 170 and 200 °C. It is more prominent at 170 °C than at 200 °C for each blend, indicating that the quench depth at 170 °C is deeper than that at 200 °C, although these blends were not quenched from a homogeneous state. The above results give strong evidence of UCST behavior of the iPP/PEOc blends, which is consistent with Yao's result [27]. Annealing at a certain temperature, the phase domain size of PEOc-40 is much larger than that of PEOc-20 correspondingly, proving that the PEOc-40 is deeper quenched and much nearer to the critical composition than PEOc-20. After a certain period of phase separation, the coarsening has converted the bicontinuous morphology to discrete domains of the minority component with the exception of the late-stage morphology of PEOc-40 annealed at 170 °C, which still looks like the coexistence of bicontinuous and dispersed morphology. According to the simulated phase diagram, the critical composition of the iPP/PEOc blend system is at about iPP40/PEOc-60 [27], as a result, PEOc-40 is near the critical composition, so it is easier to maintain its bicontinuous interconnected structure. Moreover, the viscosity of both iPP and PEOc at 170 °C is much higher than that at 200 °C, and consequently, the mobility of molecular chains may be limited to some extent. If the annealing time is much longer, may be the dispersed morphology can be observed. It should be pointed out that the quench depth in the present work is not referred to a strict meaning defined as the depth of the quenching from the binodal temperature to the annealing temperature, as the iPP/PEOc blends concerned are not quenched from the homogeneous state. Therefore, the quench depth here only represents the temperature gap between the annealing temperature and the corresponding temperature on the binodal line.

3.1.2. Scanning electron microscopy

While PCOM provides the real space morphology evolution and the coarsening of the phase domains of iPP/PEOc blends in the molten state, the SEM images offer indirect proof

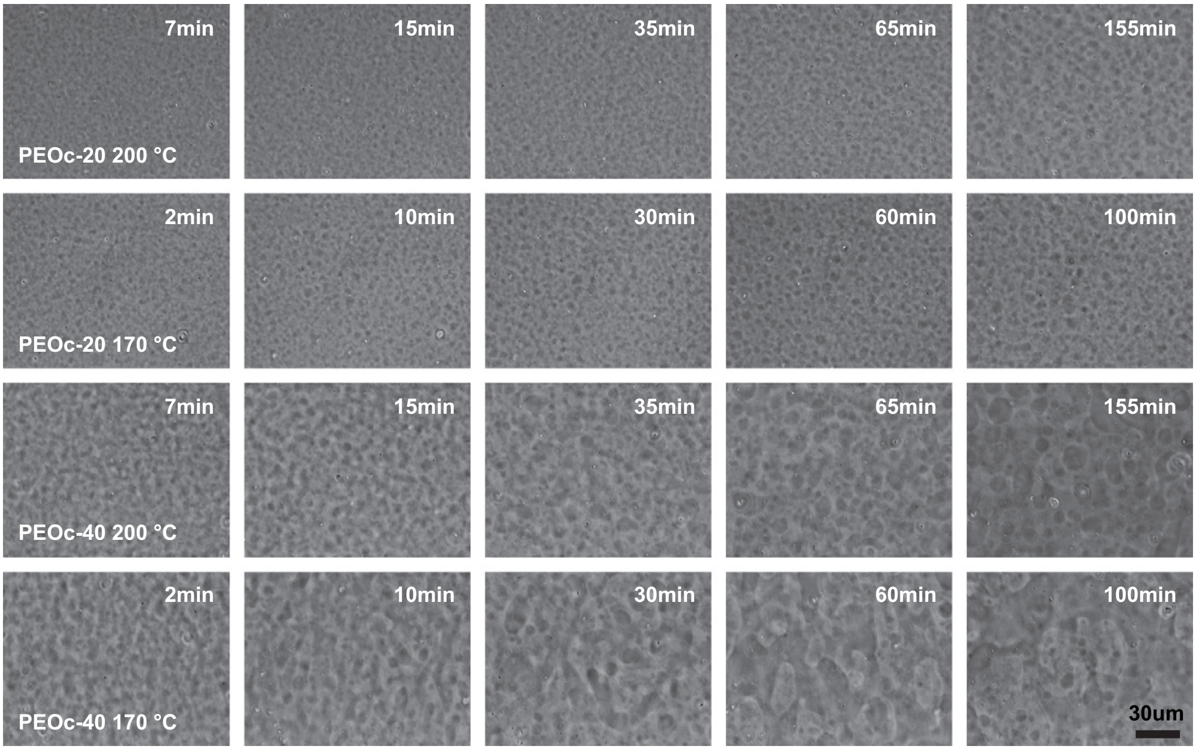

Fig. 2. Phase contrast optical micrographs of PEOc-20 and PEOc-40 annealing at 200 and 170 °C in time scale.

of the morphology development by etching the elastomer phase. Fig. 3 represents the time dependence of morphology development with phase separation proceeding. It is obvious that the size of dispersed phase increases gradually, indicating the thermodynamically spontaneous tendency towards equilibrium state. At the early stage (15 min for 200 °C and 10 min for 170 °C) of annealing at both 200 and 170 °C, the SEM images show bicontinuous interconnected structures for PEOc-40, and then gradually converts its morphology to separated phase of the PEOc-rich domain when annealing at 200 °C. However, the morphology of PEOc-40 at the late stage of annealing at 170 °C still looks like the coexistence of the bicontinuous and the dispersed structure, attributed to the bad mobility of molecular chains at lower temperature. Whereas, just a little size growth can be discerned for the separated phase domains of PEOc-20. This means that the structure evolution of PEOc-40 is more prominent than that of PEOc-20 at either 200 or 170 °C, which can be attributed to the deeper quench for the former sample. The SEM images are in good accordance with PCOM observations.

3.2. Relationship between mechanical properties and morphology evolution

3.2.1. Tensile testing and morphology evolution

The morphology dependence of mechanical properties of PEOc-20 and PEOc-40 was studied and the mechanical properties as a function of annealing time are shown in Figs. 4 and 5. It is observed that the break strength and elongation at break all decrease with increasing annealing time of the two samples, while the yield strength behaves relatively steady. Correspondingly, the data points of break strength and elongation at break can be fitted with the exponential function, while the data of the yield strength are in a linear line. The tensile properties of PEOc-20 do not change too much either being annealed at 200 °C (Fig. 4a) or at 170 °C (Fig. 5a) except at the first 30 min of the annealing process, while those of PEOc-40 (Figs. 4b and 5b) decrease more obviously as the phase morphology evolves. The slope of the changing of mechanical properties may be regarded as the reflection of the rate of phase separation. At the early stage of the annealing, the rate of phase separation is faster. As the phase separation is proceeding, the iPP-rich and PEOc-rich domains are gradually approaching to the equilibrium concentration, so the phase separation rate is slowed down. Limited by the experimental conditions, much longer time of annealing cannot be conducted to inspect the equilibrium state of phase separation. Anyway, based on the results of Figs. 4 and 5, a conclusion can be drawn that the mechanical properties of PEOc-40 are easily influenced by the morphology evolution than those of PEOc-20. As has been discussed on the POCM observations, PEOc-40 is closer to the critical composition and deeper quenched than PEOc-20 at a certain temperature, therefore, the evolution of the phase domains and the resultant mechanical properties of PEOc-40 are more prominent.

Moreover, Fig. 3 shows that in sample preparation processes, the morphology developments of the two samples are different. The coarsening changes the morphology of PEOc-40 from bicontinuous interconnected structure to

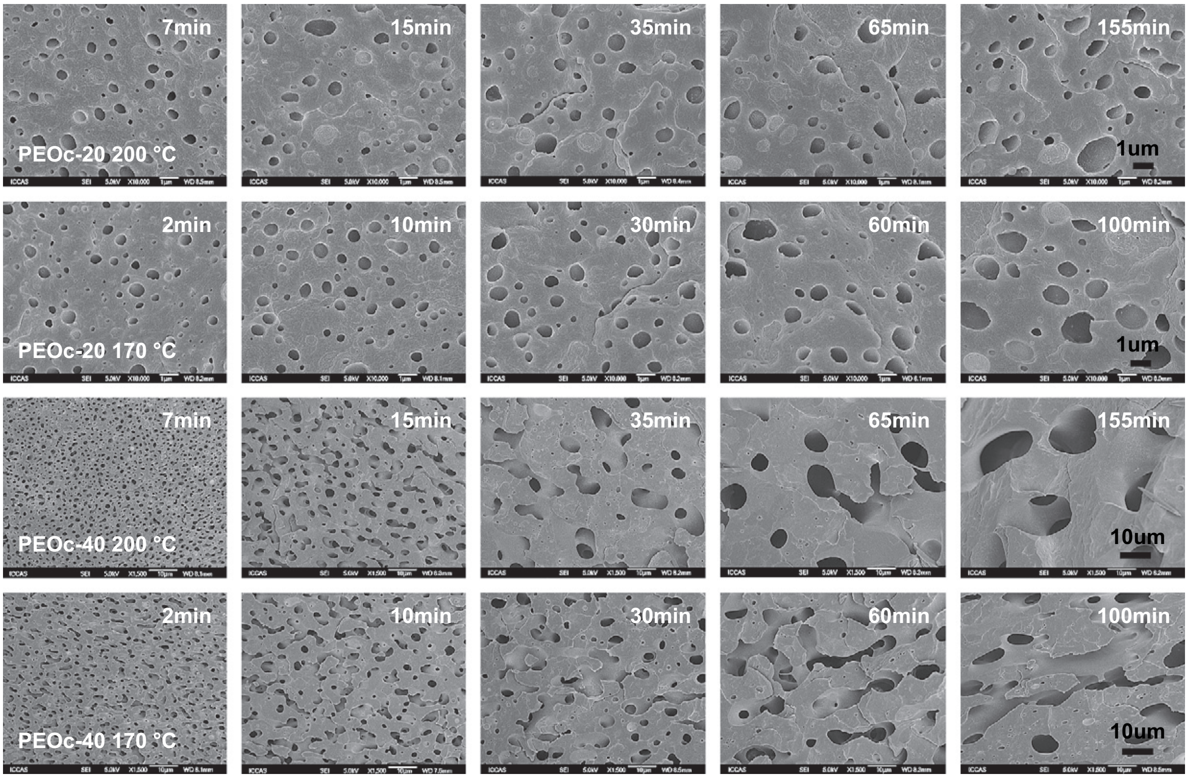

Fig. 3. SEM images of PEOc-20 and PEOc-40 at 200 and 170 °C in time scale.

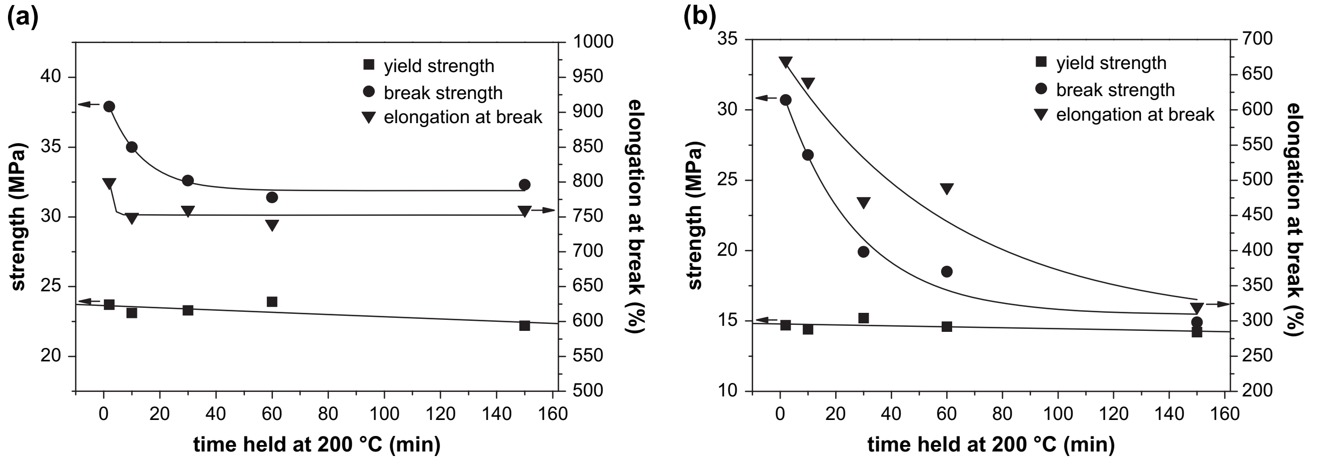

Fig. 4. Mechanical properties of tensile bars of PEOc-20 (a) and PEOc-40 (b) annealing at 200 °C for 2, 10, 30, 60 and 150 min, respectively. The lines were fitted from the corresponding data points.

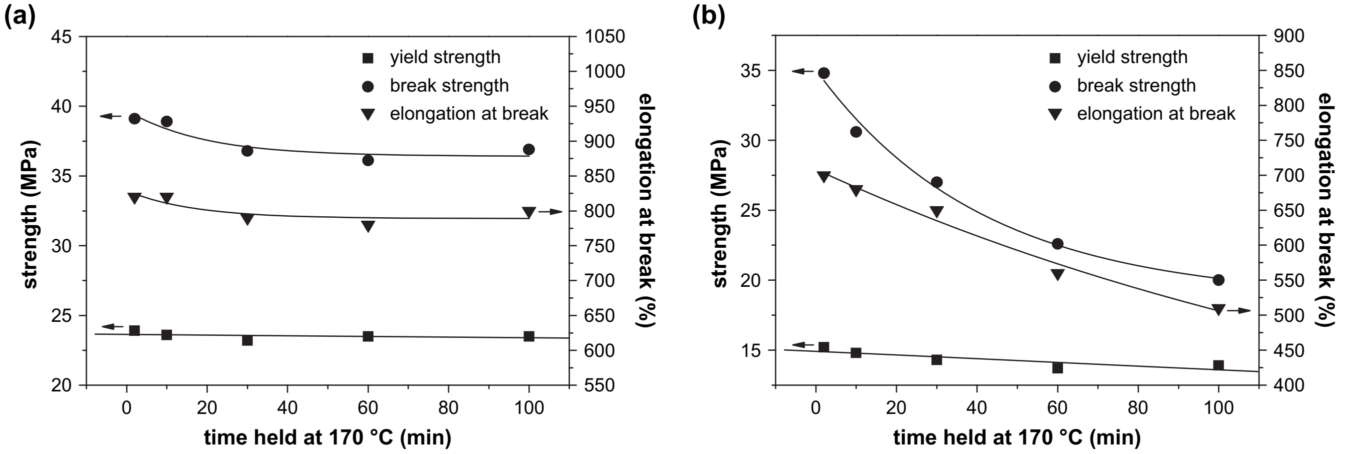

Fig. 5. Mechanical properties of tensile bars of PEOc-20 (a) and PEOc-40 (b) annealing at 170 °C for 2, 10, 30, 60 and 100 min, respectively. The lines were fitted from the corresponding data points.

dispersed morphology or coexistence of bicontinuous and dispersed structure or still bicontinuous just with size growth. Based on the experimental results and analysis, the morphology evolution should be temperature and time dependant, and annealing at lower temperature, longer time should be needed to approach to the dispersed morphology for PEOc-40. Fig. 6a and b shows the morphology evolution of PEOc-40 with the phase separation proceeding for longer time. The white and dark regions denote the iPP-rich and PEOc-rich domains, respectively. Apart from the evolution of the bicontinuous interconnected morphology into dispersed phase of the PEOc-rich domains and continuous iPP-rich phase, during the concentration fluctuation, the amount of interphase decreases and the phase boundary turns to be sharpened (Fig. 6c). The solid line and dashed lines in Fig. 6c show the concentration fluctuation at the time period of t_1 and t_2, respectively. Here t_1 is chosen as the time earlier than t_2 in the observation time scale at the late stage of phase separation. It is manifested that at the late stage of SD, with the PEOc-rich and iPP-rich domains gradually approaching to the equilibrium concentration, the interphase decreases and the phase boundary sharpens. Correspondingly, the mechanical properties including the break strength and elongation at break decrease, indicating that the less interphase and the smoother phase boundary are not propitious to the tensile deformation. Fig. 6d and e illustrates the tensile deformation of the samples with rough and smooth boundaries, respectively. It is believed that the interphase acts as tie chains or compatilizer to connect two components. Compared with the rough and diffuse boundary, the smooth phase boundary cannot retard the slippage of two phases under deformation, and resultantly, the mechanical properties become poorer. According to the previous report [30], the addition of compatilizer at a limited concentration can enhance the mechanical properties. PEOc-20 shows just a little size growth of the phase domains during phase separation (Fig. 3), which might be the origin of its better mechanical properties compared with PEOc-40.

3.2.2. Effect of quench depth on mechanical properties

The effect of quench depth in terms of compositions (PEOc-20 and PEOc-40, transverse comparison) and annealing temperatures (200 and 170 °C, longitudinal comparison)

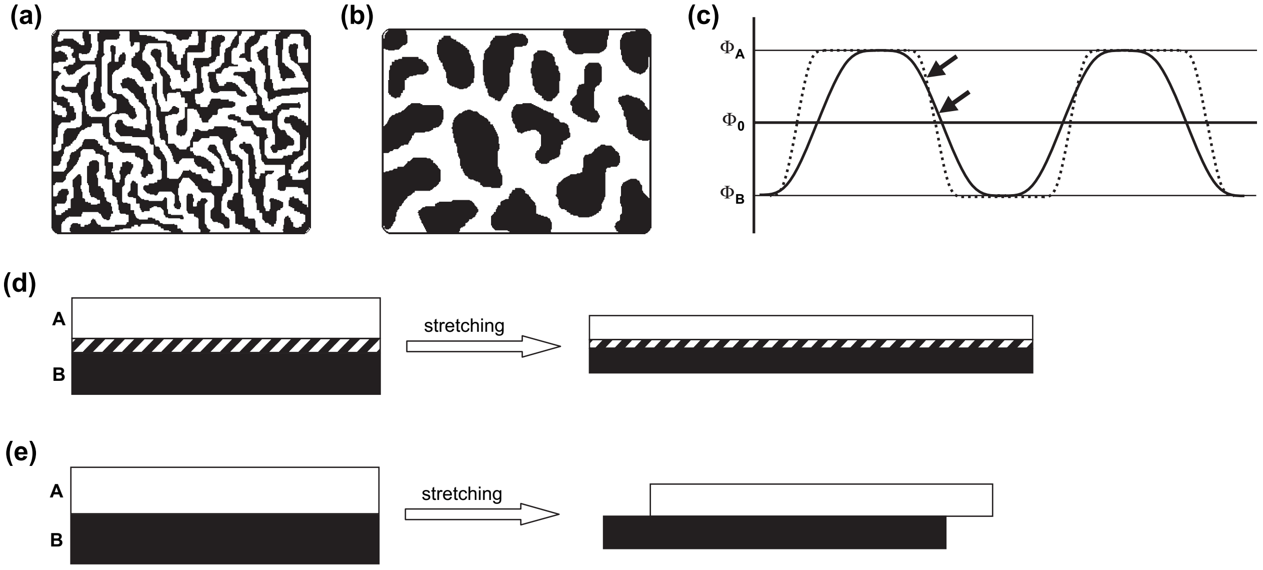

Fig. 6. The schematic illustration of coarsening process of polymer blends, which converts (a) the bicontinuous interconnected morphology into (b) the dispersed domains of the minority component. (c) Concentration fluctuation in iPP/PEOc blends at the late stage of SD. Time evolution of fluctuation is shown by solid line (t_1) and broken line (t_2, $t_2 > t_1$). Φ_A and Φ_B are the coexistence concentrations. The arrows show the interphase. Model of deformation under extensional stretching: (d) specimen with rough boundary and (e) specimen with smooth boundary.

on mechanical properties is an important topic for polymer blends. Figs. 4 and 5 show the comparison of mechanical properties between PEOc-20 and PEOc-40 annealing at 200 and 170 °C, respectively. Taking the elongation at break for an example, when the samples are annealed at 200 °C, the elongation ranges from 800 to 700% for PEOc-20, but changes from 700 to 300% for PEOc-40. And similarly, annealing at 170 °C, the elongation at break is around 800% for PEOc-20, while decreasing from 700 to 500% for PEOc-40. The break strength shows the same variation trend for the two blends. The mechanical properties of PEOc-40 change more noticeably with phase separation proceeding compared with those of PEOc-20. It can be concluded that for transverse comparison, the deeper quench depth, and the more obvious changes of mechanical properties occur in time scale. The composition closer to the critical composition is inclined to suffer from much more noticeable morphology evolution and so do the mechanical properties. Compared with PEOc-20, PEOc-40 shows poorer mechanical properties, which is not only attributed to the difference of quench depth but also to the dissimilarity of the phase domain size.

For the longitudinal comparison (temperature factor), when annealing at the temperature of a deeper quench depth, the morphology evolution should be more prominent, so does the depression of the mechanical properties. Supposedly, the mechanical properties of the samples annealing at a deeper quench depth (170 °C) should change more obviously compared with those annealing at a shallower quench depth (200 °C). Contrarily, the mechanical properties of both PEOc-20 and PEOc-40 annealing at 170 °C are experimentally better and decrease less with annealing time than those corresponding values at 200 °C. Limited by the experimental conditions, the procedures following the annealing steps at 200 and 170 °C are different and is limited by the experimental conditions, that is, a slower cooling step after annealing at 200 °C and a quenched step after annealing at 170 °C. It is believed that the influence of different crystallization processes on mechanical properties may weigh more than that of quench depths.

3.2.3. Effect of crystallization condition on mechanical properties

Not only the phase separation influences the final mechanical properties of polymer blends, but the subsequent crystallization process also plays an important role on the final performances of polymer materials, especially for the semi-crystalline polymers such as polyolefins and their blends [31,32]. The effect of crystallization on mechanical properties of iPP/PEOc blends can be estimated from Fig. 7. After PEOc-40 suffered the treatment of phase separation and then an isothermal crystallization process at 130 °C (Fig. 7b), the elongation at break and break strength became worse compared with those corresponding values of the sample just undergoing a phase separation process and then quenched to 35 °C (Fig. 7a), implying that the crystallization procedure does not facilitate the extensional deformation. The melting behavior of PEOc-40 blends prepared through two different routes was investigated, as shown in Fig. 8 and Tables 1 and 2. The heating scans exhibit two melting peaks for PEOc-40 prepared by annealing at 170 °C and then quickly quenched to 35 °C, indicating that there are two kinds of lamellae thickness. In comparison, after PEOc-40 undergoes the same annealing procedure and then an isothermal crystallization process at 130 °C for 60 min, the onset and the peak melting temperature move to higher temperature (see T_m in Table 2), and the melting enthalpy (see ΔH_m in Table 2) becomes larger

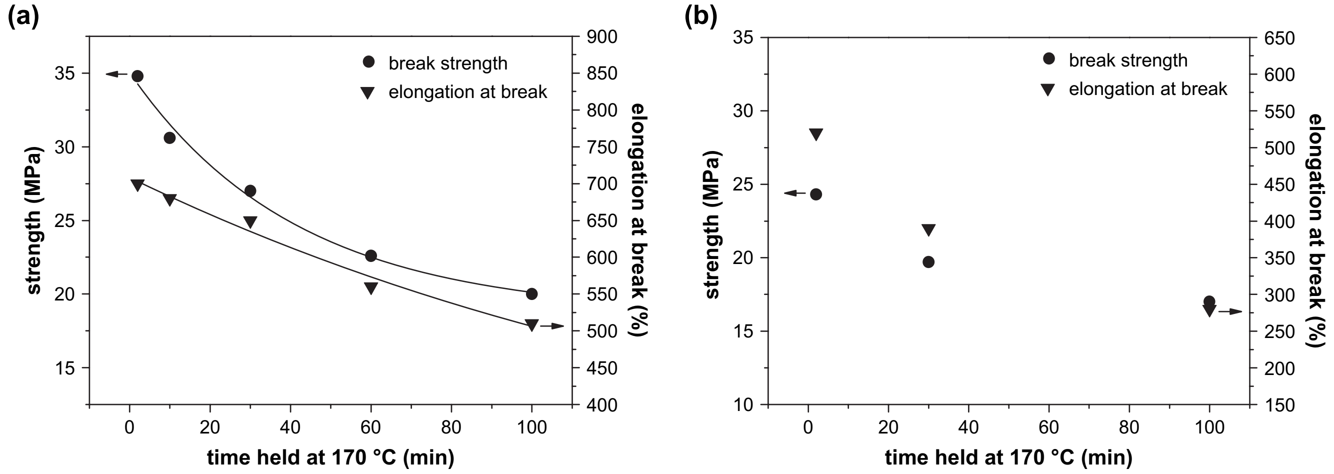

Fig. 7. (a) Mechanical properties of tensile bars of PEOc-40 annealing at 170 °C for 2, 10, 30, 60 and 100 min, respectively; (b) Mechanical properties of tensile bars of PEOc-40 annealing at 170 °C for 2, 30, and 100 min, respectively, followed by isothermal crystallization at 130 °C for 60 min. The lines were fitted from the corresponding data points.

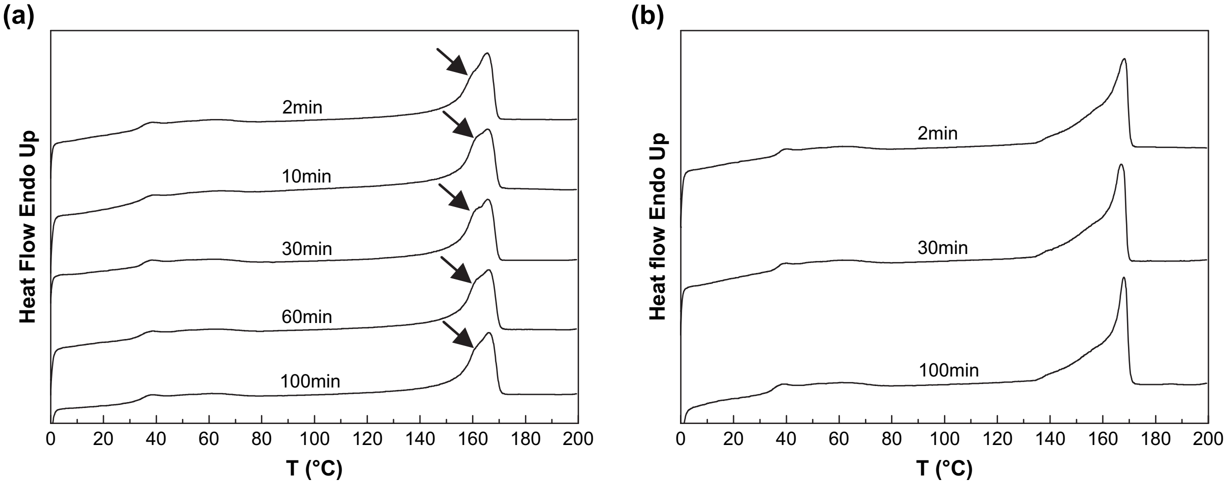

Fig. 8. The DSC heating scans of PEOc-40 prepared (a) with annealing at 170 °C for various times and then quenched to 35 °C or (b) after annealing at 170 °C for various times and then isothermally crystallizing at 130 °C for 60 min. DSC heating rate was 10 °C/min.

correspondingly, implying that the crystals are of higher perfection and the degree of crystallinity increases. To go back to the two series of samples prepared by annealing at 200 and 170 °C, it is believed that there are more crystals of higher perfection and thicker lamellae in the crystallization procedure after annealing at 200 °C than those at 170 °C, as the cooling rate is slower for the former process. Crystals of larger sizes and higher perfection cannot stand larger tensile deformation, and as a result, the mechanical properties of PEOc-20 and PEOc-40 annealing at 170 °C are better than those at 200 °C, and also those values of PEOc-40 directly quenched to 35 °C are better than those undergone the isothermal crystallization procedure. It can be concluded that the crystals of higher perfection formed at a slower cooling rate or under an isothermal crystallization process at higher temperature are not favorable for the tensile deformation. More work about the effect of crystallization conditions and crystalline structures on mechanical properties will be carried out in detail in future.

Table 1
Various parameters obtained from the heating scans of PEOc-40 prepared by annealing at 170 °C for different times and then quenched to 35 °C

Hold time at 170 °C	2 min	10 min	30 min	60 min	100 min
Onset (°C)	152.6	153.9	153.3	153.7	154.0
T_{m1} (°C)	160.4	161.9	161.7	161.9	162.1
T_{m2} (°C)	165.4	165.6	165.6	166.1	166.1
ΔH_m (J/g)	62.7	60.6	59.5	59.6	60.0

Table 2
Various parameters obtained from the heating scans of PEOc-40 prepared by annealing at 170 °C for different times and then isothermally crystallizing at 130 °C for 60 min

Hold time at 170 °C	2 min	30 min	100 min
Onset (°C)	159.7	160.6	162.7
T_m (°C)	168.3	166.9	168.0
ΔH_m (J/g)	65.7	65.4	66.4

4. Conclusions

In this paper, the time evolution of structure and the resultant mechanical properties of iPP/PEOc blends are concerned in terms of morphology development. The iPP/PEOc blends behave the UCST type and the time dependence of morphology evolution of PEOc-40 is prominent, while the size growth of PEOc-20 is just a little. Accordingly, the depression of the mechanical properties including the break strength and elongation at break is more obvious for PEOc-40 than for PEOc-20. As the phase separation proceeds, the interphase decreases and the phase boundary sharpens resulting from the concentration fluctuation, which are responsible for the poorer mechanical properties. It is believed that both the processing time and the quench depth including the composition and processing temperature dominate the morphology and the consequent mechanical properties, and the crystallization procedure also plays another important role.

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