

Polypropylene/Linear Low-Density Polyethylene Blends: Morphology, Crystal Structure, Optical, and Mechanical Properties

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ABSTRACT: The morphology, crystal structure, crystallization behavior, optical, and mechanical properties of isotactic polypropylene (iPP) blended with metallocene linear low-density polyethylene (mLLDPE) and Ziegler–Natta linear low-density polyethylene (zLLDPE), with and without nucleating agents, were investigated. The correlation between the structures and optical properties was investigated. The addition of linear low-density polyethylenes (LLDPEs), nucleating agents, and poly(ethylene-co-octene) (POE) had little influence on the crystal form of the iPP. The growth along the *b* axis was favorable in the presence of nucleating agents and LLDPEs. The LLDPEs led to much finer crystal morphologies, and the nucleating agents further prohibited spherulite formation; consequently, light scattering from the bulk crystalline structure was reduced. In all blends, biphasic morphology was observed, and POE

could improve the adhesion between the iPP and mLLDPE. After blending with LLDPEs, the haze and stiffness decreased, and the gloss increased. mLLDPE enhanced the toughness whereas zLLDPE had a slight influence on it. The nucleating agents decreased the haze, increased the gloss more, and ameliorated the stiffness; however, they changed the toughness little. POE increased the toughness of the blend significantly, accompanied by a much lower haze, higher gloss, and almost the same stiffness. When the concentration of 1,3 : 2,4-bis(3,4-dimethylbenzylidene sorbitol) exceeded 0.25 wt %, the optical properties and mechanical properties leveled off. © 2008 Wiley Periodicals, Inc. *J Appl Polym Sci* 111: 194–202, 2009

Key words: morphology; polyolefins; toughness; transparency

INTRODUCTION

At this time, the nucleating agents are widely used as additives to improve the transparency and gloss of isotactic polypropylene (iPP); this is accompanied by increased rigidity and decreased processing time.¹ The nucleating agents usually used in industry are low-molecular-weight inorganic fillers,² organic substances,^{3–6} or polymeric substances.⁷ However, the impact properties or the toughness of the transparent iPP deteriorates in general.⁸ Therefore, the end use of transparent iPP is restricted; this is more pronounced in the package industry, where both toughness and transparency of the products are required. To expand the use of transparent iPP, it is very important to enhance the toughness at the pre-condition of maintaining the transparency of iPP.

In the literature, widely used impact modifiers of iPP have been ethylene–propylene rubber and ethylene–propylene–diene terpolymer.^{9–11} Recently, a new type of impact modifier for iPP, metallocene polyethylene (mPE), was introduced to the polymer industry.¹² This new type of polyethylene (PE) showed

some excellent properties that had been unattainable from conventional Ziegler–Natta catalysts, such as a narrower molecular weight and comonomer distribution and closer control of side-chain length and degree of branching.¹² Compared to traditional impact modifiers such as ethylene–propylene–diene terpolymer, it showed a better processability and the same mechanical properties.¹³ So it has received considerable scientific attention in the literature.^{14–17} It was found that the crystallization of iPP was affected by the presence of mPE, which indicated a certain degree of miscibility between them.¹⁸ It was shown that the addition of metallocene linear low-density polyethylene (mLLDPE) improved the toughness of iPP, and the formation of the cocontinuous phase had a much superior toughness compared to a sea–island structure.¹⁹ In addition, the nucleating agent also had some influence on the crystallization behavior of an iPP/mPE blend.¹⁶ However, there have been no reports on the optical properties of such a blend.

The aim of this study was to prepare an iPP blend that had excellent optical properties and enhanced toughness and stiffness. Two different types of linear low-density polyethylenes (LLDPEs), mLLDPE and Ziegler–Natta linear low-density polyethylene (zLLDPE), were used as impact modifiers for iPP. Their effects on the morphology, crystal structure, crys-

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tallization behavior, optical properties, and mechanical properties of iPP were compared with each other. Two different nucleating agents, sorbitol acetals and rosin-based nucleating agent, were used to increase the transparency and gloss of the ultimate blends. To further improve the toughness of the blends, poly(ethylene-co-octene) (POE) was used as a compatibilizer. In addition, the effects of the concentration of the sorbitol acetals on the optical properties and mechanical properties of the blend were investigated.

EXPERIMENTAL

Materials

Commercial iPP powder without any additives, HXD-140 (Jinlin Plastic and Rubber Co., Ltd., Nanjing, China), was used directly. Two LLDPEs were used. One was mLLDPE, Harmorex NF324A (Japan Polyolefin Co., Ltd., Tokyo, Japan), and the other was zLLDPE, DFDA-7042 (Sinopec Yangzi Petrochemical Co., Ltd., Nanjing, China). A POE, TAFMER DF710 (Mitsui Polychemical Co., Ltd., Tokyo, Japan), was used as a compatibilizer. The characterization data of three resins are shown in Table I. The nucleating agents used in this research were a 1 : 1 : 1 cocrystal of potassium dehydroabietate, sodium dehydroabietate, and dehydroabietic acid (identified as NA1 and prepared according to the literature²⁰) and Millad 3988 [1,3 : 2,4-bis(3,4-dimethyl-benzylidene sorbitol), identified as NA2].

Sample preparation

Six blends of iPP and LLDPEs with or without nucleating agents were compounded in a laboratory corotating twin-screw extruder [TE-20, Coperion Keya (Nanjing) Machinery Co, Ltd., Nanjing, China] under 210°C. The melt was cooled and pelletized. The ratios of the LLDPE, POE, and nucleating agents in the blends were 30, 2.5, and 0.25 wt %, respectively. The blends were identified as PP/mLLDPE, PP/mLLDPE/NA1, PP/mLLDPE/NA2, PP/zLLDPE, PP/zLLDPE/NA1, and PP/LLDPE/POE/NA2, res-

pectively. A blank control sample of iPP was prepared in a similar way. The samples of PP/LLDPE/POE with various concentrations of NA2 were prepared in a similar way to investigate the effects of concentration of the NA2 on the properties of the blends. Samples for optical and mechanical characterizations were injection-molded with a reciprocating-screw injection-molding machine (CJ80M3V, Chen De Plastics Machinery Co., Ltd., Shunde, China).

Measurements of the optical and mechanical properties

Injected discs 1 mm thick and 50 mm in diameter were used for optical measurements. The haze of the samples was measured by a photoelectric hazemeter (WGW, Shanghai Precision & Scientific Instrument Co., Ltd., Shanghai, China) according to ISO 14782:1999. The gloss was tested with a glossmeter (WGG60-Y4, Keshijia Institute of Photoelectrical Instrument, Quanzhou, China) according to ISO 2813:1994. Three samples were measured, and the averages are reported. The impact specimens were notched, and Izod impact strength testing was carried out on an impact tester (UJ-4, Chengde Testing Machine Co., Ltd., Chengde, China) according to ISO 180:1993 at 23°C, and the impact rate was 3.5 m/s. Flexural modulus measurement was carried out according to ISO178:1993 on a universal material testing machine (SANS5254, Shenzhen Sans Testing Machine, Inc., Shenzhen, China). The flexural rate was 2 mm/min. At least five samples were measured, and the averages are reported.

Scanning electron microscopy (SEM)

Injection-molded samples were used to investigate the phase structure of these blends with and without nucleating agents. The specimens were cryogenically fractured in liquid nitrogen. To improve the contrast between the phases, the fractured surfaces of iPP/mLLDPE blends were etched in *n*-heptane for 2 h with the help of the supersonic at room temperature, and the iPP/zLLDPE blends were etched in xylene for 4 min at 80°C. After that, the surfaces were dried *in vacuo* and then coated with Au. All of the SEM images were observed on a Jeol JSM-5900 (Jeol, Japan).

Polarized optical microscopy (POM)

The morphology of these blends with and without nucleating agents was observed with a polarized light microscope equipped with cross-polars and a charged coupling device camera (LW-200-4JS, Shanghai LW Scientific Co., Ltd., Shanghai, China). A small piece of sample was clamped between two microscope glass slides, heated to 220°C and kept

TABLE I
Parameters of the Resins

Sample	Refractive index ^a	Density (g/cm ³)	Melt flow index (g/10 min) ^b
iPP	1.509	0.905	11.6
mLLDPE	1.505	0.905	1.0
zLLDPE	1.514	0.920	2.0
POE	1.487	0.870	1.2

^a The refractive index was measured according to ISO 489:1999.

^b The melt flow index was measured according to ISO 1133:1997 at 2.16 kg. The temperature was 230°C for iPP and 190°C for LLDPE and POE.

for 10 min, then squeezed on the slides and moved away from the hot stage, cooled in air to room temperature, and crystallized for 48 h.

Wide-angle X-ray diffraction (WAXD)

Samples prepared similarly to those used in POM were used to determine the crystal structure. WAXD measurements were made with an ARL X'TRA X-ray diffractometer (Thermo Electron Corp., Cambridge, MA) with a Cu K α source. The equipment was operated at 45 kV and 35 mA under ambient temperature, and the scan range was between 5 and 40° with a scan rate of 2°/min and a step size of 0.02°.

Differential scanning calorimetry (DSC)

DSC measurements were performed on a Perkin-Elmer (Cambridge, MA) Pyris 1 system under a dry nitrogen atmosphere. This apparatus was calibrated with standard indium before measurement. For each measurement, about 5 mg of extruded pellet was sealed in an aluminum pan, then heated from 50 to 220°C at a rate of 60°C/min, held at 220°C for 5 min to erase all the thermal memory, then cooled to 50°C at a constant cooling rate of 10°C/min, held for 1 min, and then heated to 220°C at a rate of 10°C/min. The heat flow versus temperature was recorded. The analysis of the melting behavior of these blends was carried out for the second run data. The crystallinity (X_c) of each component in the blends was calculated from the melting enthalpy (ΔH_m) values according to eq. (1):

$$X_c = \frac{\Delta H_m}{w\Delta H_0} \times 100\% \quad (1)$$

where ΔH_0 is the accepted value for the melting enthalpy for a 100% crystalline sample. For iPP and PE, the values of ΔH_0 were taken as 207²⁰ and 288 J/g,¹⁶ respectively. w was the weight fraction of iPP or PE in the blends.

RESULTS AND DISCUSSION

Phase structures

SEM micrographs of the cryogenic fracture surfaces of the various iPP/LLDPE blends are shown in Figure 1. As shown, a distinct biphasic or sea-island structure was present in all samples. For the iPP/mLLDPE, uniform dispersion of the particles of mLLDPE within the continuous matrix of iPP was observed [Fig. 1(b)]. The size of the dispersed particles was about 0.8–1 μm . The fracture surface also exhibited some voids, which may have been due to the fact that the particles were pulled out during

fracture. The same structure was reported elsewhere.¹⁹ After the addition of NA1 or NA2, the phase morphology changed little [Fig. 1(c,d)]. The phase morphology of the blends was mostly determined by properties such as viscosity ratio, composition, and interfacial tension.²¹ The addition of small amounts of the nucleating agents had little effects on the viscosity ratio; therefore, they had slight influence on the phase morphology of the blends. In the literature, the compatibilizer was always used to improve interfacial adhesion, and thus, the mechanical properties were improved.²² POE was partially compatible both with mLLDPE²³ and iPP;²⁴ therefore, we chose POE as a compatibilizer to improve the adhesion of iPP/mLLDPE. It was clear that POE could obviously increase the adhesion of iPP and mLLDPE. As shown, the holes observed in Figure 1(b–d) were not present in the iPP/mLLDPE/POE/NA2 anymore, the interface of iPP and mLLDPE became blurry and the discrepancy of the interface between the iPP and mLLDPE diminished; this must have had some obverse effects on the optical and mechanical properties of the blend. For the iPP/zLLDPE, a continuous structure with many holes was observed. The holes were the zLLDPE particles removed by the etching of xylene during samples preparation. Compared to iPP/mLLDPE, the shape of dispersed zLLDPE particles was more irregular, and the distribution of the particles sizes was much broader than that of mLLDPE in iPP. Moreover, the addition of NA1 also did not influence the phase morphology, as expected.

Crystal morphology

Figure 2 shows the POM images of iPP/LLDPE with and without nucleating agents. It is clearly shown that the blank iPP [Fig. 2(a)], mLLDPE [Fig. 2(g)], and zLLDPE [Fig. 2(h)] presented the typical spherulite structures. The diameter of the blank iPP was about 40 μm [Fig. 2(a)], and it had the biggest spherulites in these samples. The values for mLLDPE and zLLDPE were about 20 and 10 μm , respectively. After the addition of LLDPE, the size of the spherulites of iPP decreased, and the spherulites became misshapen, which indicated that the crystallization of iPP was disturbed by the LLDPEs, and the iPP chain segments were more difficult to arrange in an ordered manner than those of the pure iPP. Therefore, the misshapen spherulites formed.²⁵ When 0.25 wt % nucleating agent was added, the sizes of the spherulites decreased drastically, the formation of the spherulites was prohibited, and a very fine and uniform morphology was observed. This was the reason why the blends containing nucleating agents presented excellent transparency and gloss, which is discussed in the latter part of this article. The same

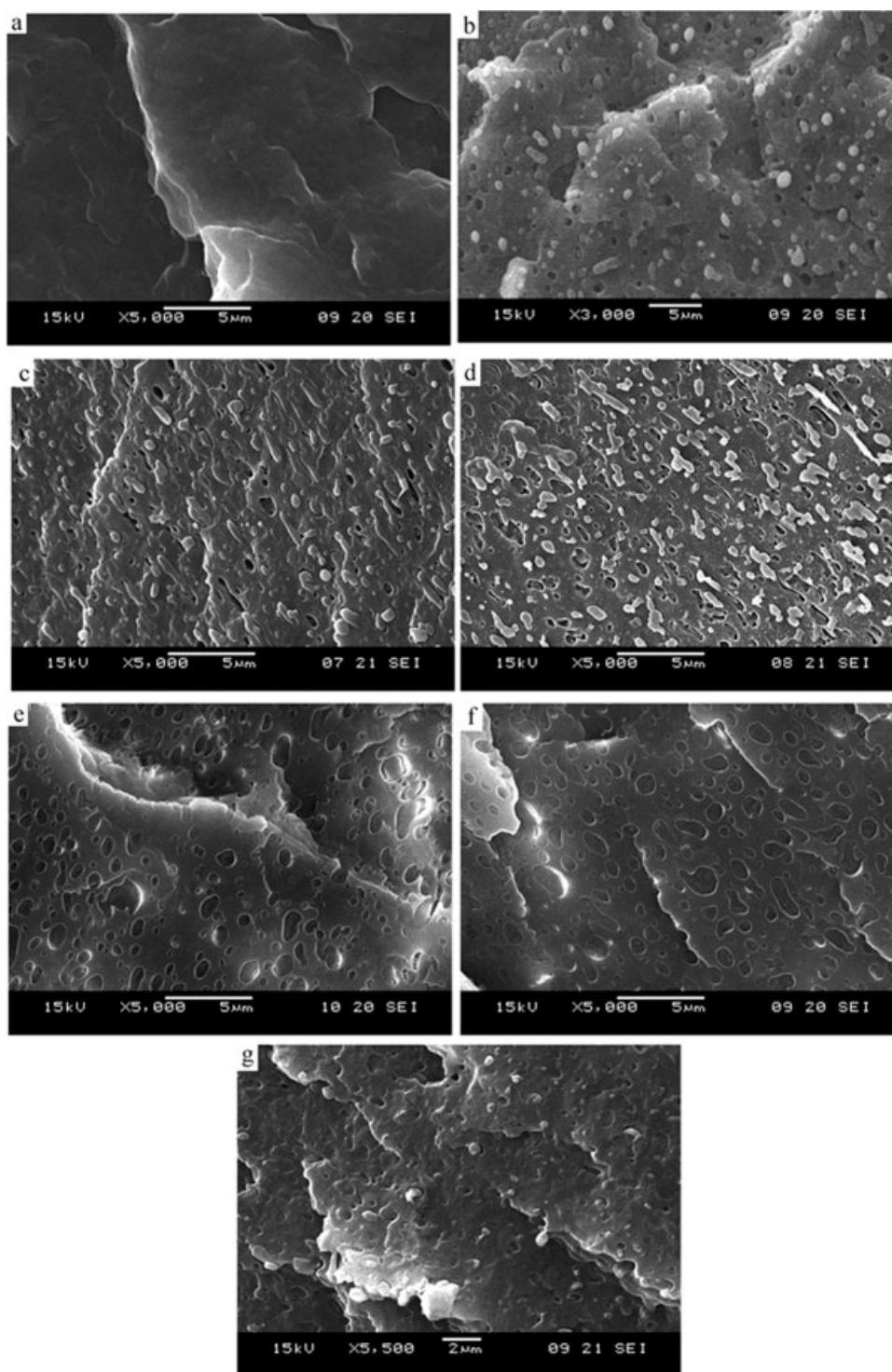


Figure 1 SEM micrographs of iPP/LLDPE: (a) blank iPP, (b) iPP/mLLDPE, (c) iPP/mLLDPE/NA1, (d) iPP/mLLDPE/NA2, (e) iPP/zLLDPE, (f) iPP/zLLDPE/NA1, and (g) iPP/mLLDPE/POE/NA2.

structure was reported in the literature.^{16,26} The picture of iPP/mLLDPE/NA1 is not shown because its crystal morphology was very similar to that of iPP/mLLDPE/NA2. Moreover, it seemed that the addition of 2.5 wt % POE had slight influence on the crystal morphology of the blend [Fig. 2(d)].

Crystal structure

Figure 3 presents the WAXD patterns of various iPP/LLDPE blends. For the blank iPP, only the monoclinic α phase is presented because of the characteristic reflections at the following angles, $2\theta = 14.2, 17.0, 18.8, 21.2,$ and 22.0° , corresponding to the following

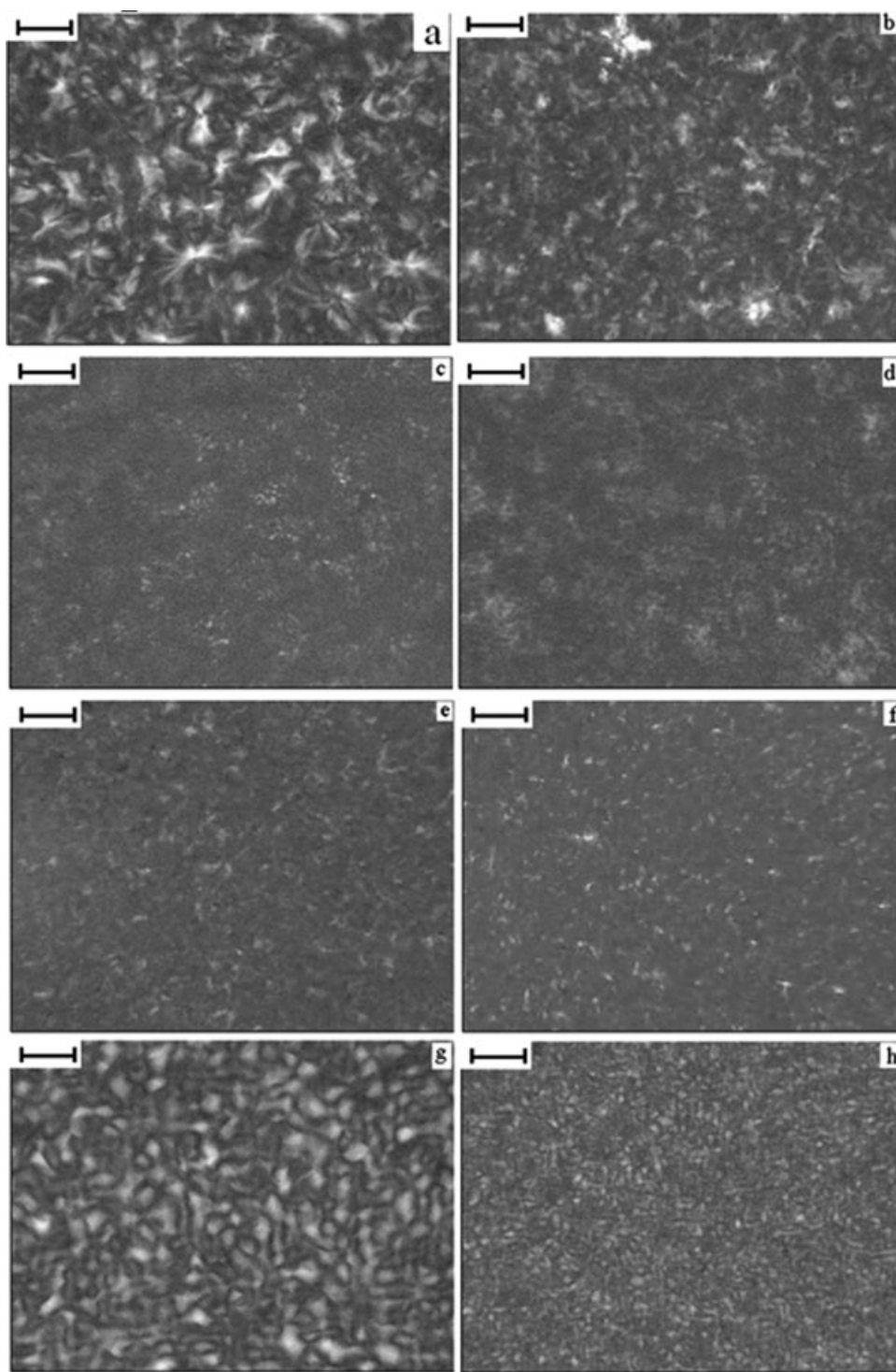


Figure 2 POM images of (a) blank iPP, (b) iPP/mLLDPE, (c) iPP/mLLDPE/NA2, (d) iPP/mLLDPE/POE/NA2, (e) iPP/zLLDPE, (f) iPP/zLLDPE/NA1, (g) mLLDPE, and (h) zLLDPE. The scale bar was 20 μm .

respective crystalline planes: (110), (040), (130), (111), and (041) of the α -iPP.²⁷ In both mLLDPE and zLLDPE, only the orthorhombic form presented because of the 110 and 200 reflections at 2θ values of 21.7 and 23.9°, respectively.²⁸ The patterns of iPP/mLLDPE and iPP/zLLDPE were a simple addition to that of the iPP and mLLDPE or zLLDPE; no new

reflection or any measurable shift of the diffraction peaks were observed. However, the amorphous background was increased by mLLDPE and zLLDPE, which indicated that the crystallinity of the blends decreased. The addition of nucleating agent had no effect on the crystal form of iPP or mLLDPE, but the amorphous background decreased a little, which

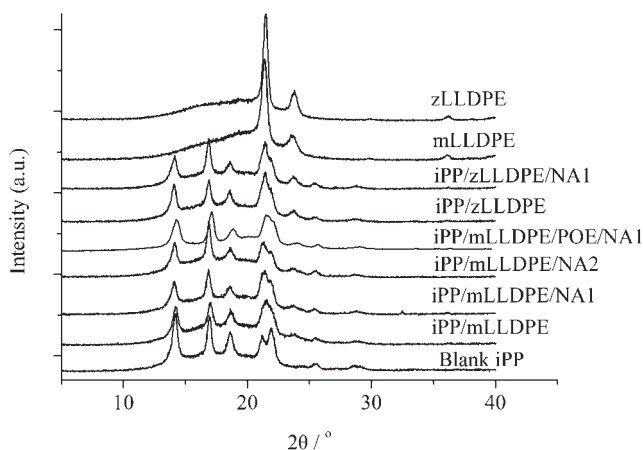


Figure 3 WAXD patterns of various iPP/LLDPE blends.

indicated an increase in the crystallinity. However, it was difficult to accurately determine the crystallinity of the blends with WAXD because of the overlapping amorphous backgrounds of the iPP and LLDPEs, and the amorphous halo could not be separated for each component correctly. POE also had no effects on the crystal form of iPP or mLLDPE, but the position of the diffraction peaks shifted a little to the high 2θ range, which indicated that the iPP and mLLDPE had some interaction during crystallization, which accorded with the results of SEM.

In the blends, some phenomena related to the unit cell of the iPP were observed. The LLDPE, nucleating agents, and POE changed the intensities of the first two reflections of iPP [(110) and (040) face]. For the blank iPP, the intensity of (110) was greater than that of (040); after the addition of LLDPEs and nucleating agents, (040) was more intense than (110), which indicated that growth along the b axis was preferential during crystallization.²⁰ The other fact was the change of the full width at half-maximum (fwhm). It is known that the perfection of the α -iPP can be evaluated from the fwhm of (110) at $2\theta = 14.1^\circ$.²⁹ The addition of mLLDPE increased the fwhm of (110) of iPP, which indicated that the packing order of α -iPP decreased; this quite agreed with the results of POM. After the addition of the nucleating agents, the values of fwhm decreased, which meant that the packing order increased, and NA2 had more pronounced effects than NA1. The same trends were observed in the blends of iPP/zLLDPE. Moreover, the POE led to more disordered packing of the α -iPP because it could act as a compatibilizer; thus, the interaction between iPP and mLLDPE was more pronounced, and the crystallization of iPP was disturbed by the mLLDPE in the presence of POE.

Crystallization and melting behavior

Figure 4 shows the crystallization and melting behavior of these blends with and without nucleat-

ing agents. The crystallization peak temperature, melting peak temperature, and crystallinity of iPP and LLDPEs in these samples, which were analyzed from these DSC curves, are listed in Table II. As shown, iPP showed a crystallization exotherm at 114°C with a crystallinity of 42% (Table II). mLLDPE had a crystallization peak located at 103°C and a crystallinity of 21%, whereas zLLDPE showed a crystallization peak temperature at 104°C and a crystallinity of 29%. In the blend of PP/mLLDPE, the crystallization of iPP took place at the same temperature as that of the blank iPP, and the crystallization peak of mLLDPE was overlapped with that of the iPP in the range 103 – 110°C ; therefore, it was difficult to determine the crystallization peak temperature of mLLDPE accurately. In this blend, the crystallinity of both components was decreased obviously, especially for mLLDPE (Table II). For the PP/zLLDPE blend, both crystallization of iPP and zLLDPE was observed. The crystallization peak temperature of iPP shifted to 116°C , and the crystallization peak temperature of zLLDPE moved to 111°C , accompanied by an obvious decrease in the crystallinity of both components. This indicated that during crystallization, some interaction between iPP and LLDPEs

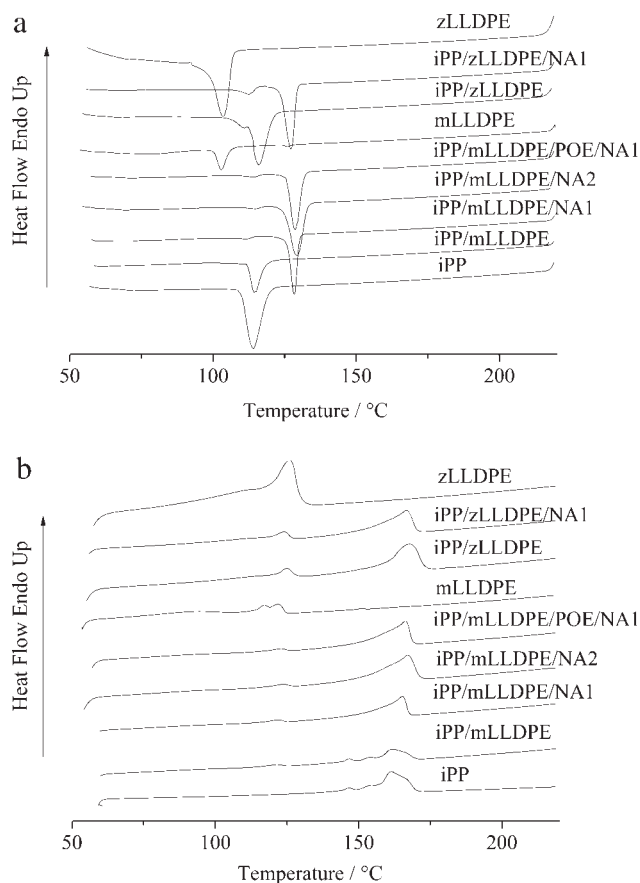


Figure 4 (a) Crystallization and (b) melting behavior of various iPP/LLDPE blends.

TABLE II
Crystallinity, Crystallization, and Melting Peak Temperatures of iPP and LLDPEs in iPP/LLDPE with and Without Nucleating Agents

	Crystallinity (%)		Melting peak temperature (°C)		Crystallization peak temperature (°C)	
	iPP	LLDPE	iPP	LLDPE	iPP	LLDPE
Blank iPP	42	—	162	—	114	—
PP/mLLDPE	34	5	162	121	114	—
PP/mLLDPE/NA1	38	9	165	121	128	112
PP/mLLDPE/NA2	41	9	167	124	128	113
PP/mLLDPE/POE/NA2	38	8	166	123	129	114
mLLDPE	—	21	—	122	—	103
PP/zLLDPE	36	10	168	125	116	111
PP/zLLDPE/NA1	40	11	167	124	127	113
zLLDPE	—	29	—	126	—	104

was present. Compared to the nonnucleated blends, the incorporation of nucleating agents significantly increased the crystallization peak temperatures of iPP and the LLDPEs, which was accompanied by little increased crystallinity. The same trend was reported in the literature, and it was due to the nucleation effects of the nucleating agents.¹⁶ In Table II, it is clearly shown that POE slightly increased the crystallization peak temperature of iPP and mLLDPE but decreased little the crystallinity of iPP and mLLDPE in PP/mLLDPE/POE/NA2. POE in this system might have had two effects. First, the presence of noncrystalline POE facilitated the dispersion of nucleating agent and, thus, enhanced its nucleation ability and led to an increased crystallization peak temperature in both components. Second, as a compatibilizer, POE had some compatibility between the iPP and mLLDPE; the noncrystalline component might have disturbed their crystallization a little, thus slightly decreasing their crystallinity.

Optical and mechanical properties

Table III shows the optical properties and mechanical properties of the blends of iPP/LLDPE with and without nucleating agents. Compared to the blank iPP, both mLLDPE and zLLDPE decreased the haze and increased the gloss, and mLLDPE had more pro-

nounced effects than zLLDPE (Table III). After it was blended with 30 wt % mLLDPE, the haze of iPP decreased by more than 60%, and the gloss increased by 20%; the corresponding values of iPP/zLLDPE were about 50 and 19%, respectively. It is known that in semicrystalline polymers, the crystalline structure in the bulk is an important source of light scattering,³⁰ and in multiphase polymer blends, the light scattering on the interface is another important contribution to the haze.³¹ As shown by POM and WAXD, the addition of the two LLDPEs led to the formation of a more disordered and finer structure of iPP; therefore, the light scattered by the bulk crystalline structure decreased, and the optical properties were ameliorated. The refractive indices of the LLDPEs were close to that of iPP. The misfit of the refractive index of iPP with mLLDPE was 0.26%, and the value for iPP and zLLDPE was 0.33%, so the blending of iPP with such LLDPEs may had little influence on the ultimate optical properties because the light scattering on the interface of the iPP/LLDPEs was very little.³¹ The combination of these two facts led to the decreased haze and increased gloss of the blends. Moreover, the misfit of the refractive index between iPP and zLLDPE was a little more than that of iPP and mLLDPE; this must have had a slight adverse effects on the optical properties. With the addition of 0.25 wt % nucleating agent, the

TABLE III
Optical and Mechanical Properties of iPP/LLDPE with and Without Nucleating Agents

	Impact strength (kJ/m ²)	Flexural modulus (MPa)	Haze (%)	Gloss (%)
Blank iPP	3.03 ± 0.05	1537 ± 28	50.4 ± 1.3	97.2 ± 2.0
PP/mLLDPE	5.46 ± 0.01	971 ± 68	18.7 ± 0.9	119.0 ± 0.5
PP/mLLDPE/NA1	5.44 ± 0.05	1165 ± 31	10.8 ± 1.3	126.5 ± 1.8
PP/mLLDPE/NA2	5.55 ± 0.11	1096 ± 19	10.3 ± 1.0	131.1 ± 1.1
PP/zLLDPE	3.41 ± 0.14	968 ± 23	24.9 ± 2.0	116.1 ± 1.8
PP/zLLDPE/NA1	3.12 ± 0.04	1171 ± 27	13.9 ± 1.5	123.8 ± 1.0
PP/mLLDPE/POE/NA2	21.14 ± 2.21	1113 ± 43	9.6 ± 1.3	133.1 ± 0.8

optical properties of the blends were significantly improved. For the iPP/mLLDPE blends, the haze was close to 10%, and the gloss was bigger than 125%; the corresponding value for iPP/zLLDPE was about 14 and 124%, respectively. As shown by POM, the nucleating agents prohibited spherulite formation, and a much finer structure formed after the addition of nucleating agent; this, thus, depressed the spatial size of polarizability fluctuation in the bulk, which was smaller than the wavelength of visible light. Consequently, light scattering from the bulk crystalline structure was reduced.³² Compared to NA1, NA2 had more attractive effects on the optical properties of the blends. Compared to zLLDPE, mLLDPE improved the optical properties more obviously.

Another aim of blending iPP with LLDPEs was to increase mechanical properties. As shown, the addition of LLDPEs obviously decreased the flexural modulus; this was due to the fact that the addition of LLDPEs decreased the crystallinity of the iPP, as shown by WAXD and DSC. With the addition of nucleating agents, the flexural modulus increased a little. However, different types of LLDPEs had different influences on the toughness of iPP. mLLDPE increased the impact strength of iPP about 80%, whereas zLLDPE had little effect on the toughness. The toughness of the nucleated samples had the same value of impact strength, compared to the corresponding blank blends. The discrepancy of the mechanical properties between blends containing different nucleating agents was not obvious. This was quite reasonable because it is well known that the mechanical properties, especially the toughness, mostly depend on the phase morphology of the blends and the nature of the impact modifiers.²¹ The phase morphology of the blends was mostly determined by properties such as the viscosity ratio, composition, and interfacial tension; the addition of small amounts of nucleating agents had little effect on the viscosity ratio. Therefore, they had slight influence on the phase morphology of the blends. So the toughness of the blends changed little with the addition of nucleating agents. However, the nucleating agents increased the crystallinity of the blends, and thus, the stiffness increased. Moreover, the skin layer of iPP was enhanced through nucleation, and the highly oriented skin layer resulted in a higher stiffness of the blend. With the addition of 2.5 wt % POE, the impact strength of iPP/mLLDPE/NA2 increased drastically, which was accompanied by no loss in stiffness. The impact strength of PP/LLDPE/POE/NA2 was three times more than that of iPP/mLLDPE/NA2. Moreover, POE also led to a little decreased haze and increased gloss. This was ascribed to the facts that the POE improved the adhesion of iPP and mLLDPE and the interface was

blurry; thus, the light scattering on the interface decreased, and the optical properties improved.

Effects of the concentration of the nucleating agent

It is well known that the concentration of nucleating agents has some effects on the optical properties of iPP,²⁰ so it was quite reasonable to speculate that it would also have some influence on the iPP blends. Therefore, it was important to investigate the effects of nucleating agent on the optical properties and mechanical properties of the iPP blends. As stated previously, the blend of iPP/mLLDPE/POE with 0.25 wt % NA2 showed the best optical properties and mechanical properties; therefore, we chose it as a model to investigate the effects of the nucleating agents on the optical and mechanical properties. Figure 5 presents the optical properties and mechanical properties of iPP/mLLDPE/POE with different concentrations of NA2. As expected, the concentration of NA2 had no influence on the toughness of the blend when the errors of the experiment were considered. With increasing concentration of NA2, the haze decreased, and the gloss and flexural modulus

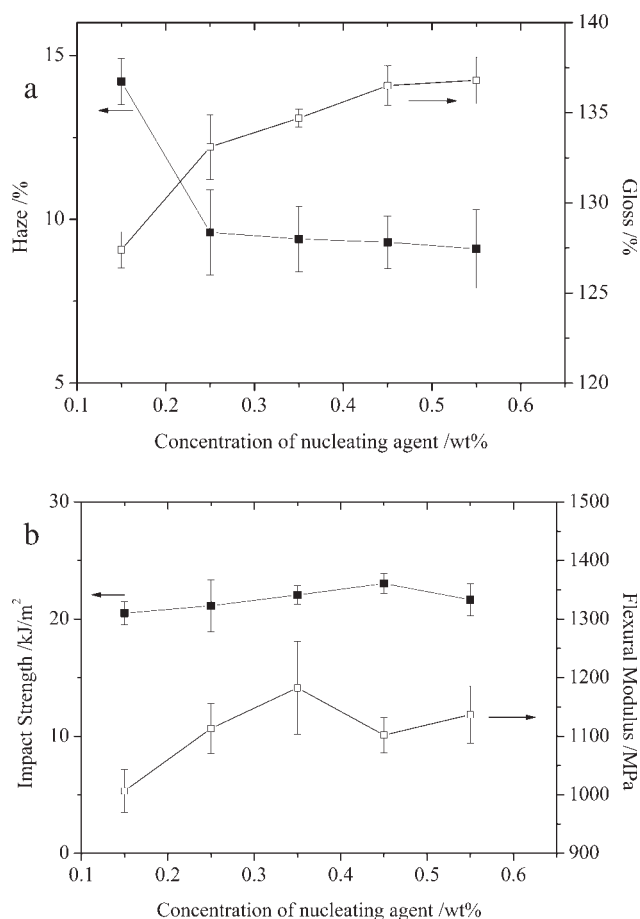


Figure 5 (a) Optical and (b) mechanical properties of iPP/mLLDPE/POE with different concentrations of NA2.

increased; however, when the concentration of NA2 exceeded 0.25 wt %, the change was little when the errors of the experiment were taken into account. NA2 had a critical concentration in the iPP, and it was 0.2 wt %.³³ If the concentration of NA2 exceeded it, the properties of iPP were independent of the concentration of NA2. In our case, the effects of NA2 in the blends were similar to those of iPP.

CONCLUSIONS

The morphology, crystal structure, crystallization behavior, optical properties, and mechanical properties of two blends, iPP/mLLDPE and iPP/zLLDPE, with and without different nucleating agents were investigated. The addition of LLDPEs, nucleating agents, and POE had little influence on the crystal form of iPP but led to a change in the unit cell of iPP. They also had some effects on the phase morphology and crystal morphology. The LLDPEs and nucleating agents led to a much finer crystal morphology; this had an important impact on the optical properties of these blends. In the blends, a biphasic morphology was observed, and POE improved the adhesion between iPP and mLLDPE. After blending with LLDPEs, the haze decreased, the gloss increased, and the stiffness decreased. mLLDPE enhanced the toughness, whereas zLLDPE had slight influence on it. The nucleating agents further decreased the haze, increased the gloss, and ameliorated the stiffness; however, they changed the toughness little. Compared to NA1, NA2 had somewhat of an advantage on the optical properties of the blend. After the addition of 2.5 wt % POE as a compatibilizer, the toughness of the blend increased significantly, accompanied by a much lower haze, higher gloss, and almost the same stiffness, compared to those of iPP/mLLDPE/NA2. If the concentration of NA2 in the blend of iPP/mLLDPE/POE exceeded 0.25 wt %, the optical properties and mechanical properties leveled off, and the blend showed excellent optical and mechanical properties.

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