Structure and Mechanical Properties of Uniaxially Oriented Films of Syndiotactic Polystyrene and Poly(2,6-dimethyl-1,4-phenylene oxide) Blends

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ABSTRACT: The structure and mechanical properties of highly oriented films of a miscible blend of syndiotactic polystyrene and poly(2,6-dimethylphenylene-1,4-oxide) (sPS/PPO) were studied in the composition range of sPS/PPO = 10/0 to 5/5. The oriented films were prepared by stretching the amorphous films of the blends. Wide-angle X-ray diffraction and polarized FTIR spectroscopy were used to analyze the amount of mesophase and molecular orientation. Drawing of the amorphous films of sPS and sPS/PPO blend induced a highly oriented mesophase. The mesophase content increases with increasing draw ratio and becomes nearly constant above a draw ratio of 3. Under the same draw ratio, the mesophase content decreases with increasing PPO content. The orientation function in the mesophase is as high as 0.95–0.99 irrespective of the composition and draw ratio. On the other hand, the orientation of molecular chains in the amorphous phase and mesophase increases with increasing draw ratio, and it decreases with increasing PPO content. The drawn films of pure sPS show high strength and high modulus in the drawing direction, but exhibit low strength in the direction perpendicular to the drawing. In the case of sPS/PPO = 7/3 blend, however, the ultimate strength in the perpendicular direction was dramatically improved compared with that of pure sPS and the ultimate strength in the parallel direction was similar to that for the oriented pure sPS. The improved mechanical properties in the sPS/PPO blends were discussed in relation to the structural characteristics of the sPS/PPO blend system. © 2004 Wiley Periodicals, Inc. J Appl Polym Sci 91: 2789–2797, 2004

Key words: blends; mechanical properties; orientation; polystyrene; syndiotactic

INTRODUCTION

Polymer blends have attracted the interest of scientists for the last two decades not only from the scientific point of view but also from the potentiality for commercial ends. Extensive studies have been carried out on polymer blends from various aspects, including the mechanical properties, phase diagrams, morphological features, and so forth. On the other hand, the orientation of polymer chains is also one of the important factors in controlling the physical properties of polymers. Therefore, there are some reports regarding the orientation behaviors of miscible polymer blends.[1–11] The orientation behaviors of the two components in a blend are not necessarily similar to those in the pure component.[1–7] The molecular orientation and its relaxation of polystyrene/poly(2,6-dimethyl-1,4-phenylene oxide) (PS/PPO) blends have been

studied during and after uniaxial deformation above the glass-transition temperature (T_g).[1–5] Monnerie et al.[1–3] reported that orientation functions of both components were higher in the PS/PPO blends than those in the pure polymers. Prud'home et al.[4,5] studied the orientation behaviors of the isolated chains of PPO in the PS matrix and reported a much higher orientation of molecular chains of PPO than that of PS chains, which was explained by the higher entanglement density of isolated PPO chains compared with that of PS chains. Molecular orientation and mechanical properties of PS/poly(vinyl methyl ether) (PVME) have been investigated in the broad composition range.[6,7] Young's modulus and the degree of orientation progressively increased with increasing PVME content from 0.3 to 0.5.

The orientation studies of polymer blends have been extended to miscible blends containing crystalline polymers. The crystallization and orientation behaviors were studied for the poly(ε-caprolactone) (PCL)/poly(vinyl chloride) (PVC) system.[8,9] It was found that the mode of orientation of PCL depended on the rate of crystallization and draw ratio; crystallization under strain led to a crystalline orientation perpendicular to the strain direction under most conditions, whereas a parallel crystalline orientation was

observed when the crystallization was rapid and the draw ratio was high. The oriented crystallization for the isotactic polystyrene (iPS)/poly(phenylene oxide) (PPO) blend was examined in our laboratory.[10] The *c*-axis of iPS crystals was found to orient parallel to the stretching direction, but the orientation of the amorphous chains of PPO was relaxed. The mechanical properties for the iPS/PPO blend were improved compared with those obtained for oriented pure iPS. Biacakci and Cakmak[11] recently reported the uniaxial drawing behaviors of the PEEK/PEI blend system. They showed that a highly structured physical network was formed during uniaxial deformation, and that oriented crystallites act as nodes in the network structure. The crystalline domains increased very rapidly with the draw ratio, and the tie chains were aligned in the direction of drawing, forming the network among the crystallites.

On the other hand, syndiotactic polystyrene (sPS) is a commercially potential polymer in our global market because of its dimensional, thermal, and chemical stabilities. This polymer shows four kinds of crystal structure: the α- and β-forms with all-*trans* conformation and the γ- and δ-forms with *trans– trans– gauche– gauche* conformation.[12–14] sPS is miscible with PPO in all composition ranges in the amorphous phase, as evidenced by the observation of a single T_g in the DSC curve.[15–17] It was reported that the oriented mesophase with conformational order was induced by stretching of the amorphous films of sPS.[18,19] The drawing behavior of sPS was also studied as a function of drawing temperature and draw ratio.[20] It was shown that the oriented mesophase consisted of small and imperfect crystals of the α-crystalline form.[21] We recently reported the effects of oriented mesophase on the oriented crystallization of sPS and sPS/PPO blends.[22] In this work, we studied the structure and mechanical properties of uniaxially drawn films of sPS/PPO blends and further discussed the structure–property relationship. Wide-angle X-ray diffraction (WAXD) and polarized FTIR spectroscopy were used to analyze the amount of mesophase and molecular orientation. The mechanical properties were measured not only in the stretching direction but also in the vertical direction.

EXPERIMENTAL

Sample preparation

Samples used in this work were syndiotactic polystyrene (>90% syndiotacticity) with weight- and number-average molecular weights M_w = 209,000 and M_n = 78,000, respectively; and poly(2,6-dimethylphenylene-1,4-oxide) with M_w = 50,000 and a polydispersity of 1.9. The samples of sPS and PPO were obtained from Scientific Polymer Products, Inc. The sPS/PPO

blends with molar ratios of 7/3 and 5/5 were prepared by casting chlorobenzene solution with a concentration of 0.4–0.6 wt %. The films were dried at 80°C under vacuum for 2 days to remove the solvent. The films were then melt-quenched in ice water at 0°C after hot pressing under nitrogen atmosphere at 300°C to obtain amorphous blend films. The amorphous films of pure sPS were obtained by quenching the molten films in the same way as for the blend films.

Samples were stretched to various draw ratios using a hand-operated stretching instrument in an air-circulating environmental cabinet at controlled temperatures within a temperature accuracy of ±1.5°C. The drawing temperature was set at 105, 130, and 150°C for pure sPS, sPS/PPO = 7/3, and sPS/PPO = 5/5, respectively. The drawing temperatures are higher than the glass-transition temperatures of the three samples by a similar degree (5–10°C) in every case. The samples can be drawn to a higher draw ratio at a higher drawing temperature but the orientation is significantly relaxed. On the other hand, it is difficult to stretch the samples at lower temperatures than the drawing temperature studied in this work.

Characterization

WAXD measurements were made using a monochromatized Cu–K$_\alpha$ radiation of wavelength 0.1542 nm (40 kV, 300 mA) generated by a Rint 2500 VH/PC X-ray diffractometer (Rigaku Denki Co., Akishima, Japan). The WAXD image was obtained using an imaging plate (IP) as a detector, and digitized data were then read from the IP using an R-AXIS-DS imaging-plate reader (Rigaku Denki). The WAXD profiles obtained from the IP image were corrected for background by subtracting the contribution of air scattering from the observed profile. The orientation functions of mesophase were calculated from the azimuthal intensity distribution of the meridional reflection at $2\theta = 35.3°$, which was measured by rotating the sample at the fixed angle of 2θ.

The polarized FTIR spectra were recorded at a resolution of 4 cm^{-1} with a Bio-Rad FTS 60A-686 FTIR spectrophotometer (Bio-Rad, Hercules, CA) equipped with a wire-grid polarizer. The dichroic ratio was obtained from the ratio of the integrated intensity of the infrared absorption band for parallel polarization to that for perpendicular polarization.

Mechanical properties were measured not only in the drawing direction, but also in the direction perpendicular to the drawing. Rectangular specimens 2 mm wide and 20 mm long were cut from the samples, and were used for tensile tests. Tensile tests were carried out at 20°C and 50% relative humidity, using a Tensilon UMT-300 (Orientec Co., Tokyo, Japan) at a strain rate of 0.2/min and at a grip-to-grip distance of 10 mm. Dynamic mechanical properties were mea-
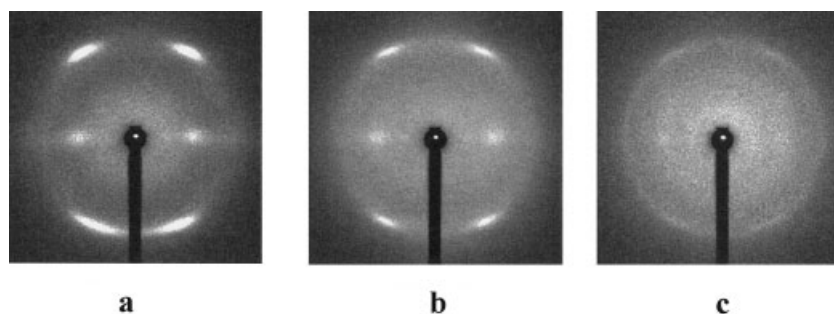
Figure 1 WAXD diagrams of drawn samples: (a) sPS; (b) sPS/PPO = 7/3 blend; (c) sPS/PPO = 5/5 blend.

sured from −150 to 230°C at a heating rate of 2 K/min under a nitrogen stream using a dynamic mechanical analyzer (DMA), Perkin–Elmer DMA 7e (Perkin Elmer Cetus Instruments, Norwalk, CT). The rectangular specimen with the dimensions of 2×15 mm^2 was cut from the samples and mounted on the DMA instrument with a grip-to-grip distance of 9–11 mm. The dynamic strain with a frequency of 1 Hz and amplitude of 7–8 μm, as well as the static strain, which was set to be 150% of the dynamic strain, was applied to the sample.

RESULTS AND DISCUSSION

Formation of oriented mesophase

Figure 1 shows the representative WAXD diagrams of drawn samples of pure sPS, sPS/PPO = 7/3, and sPS/PPO = 5/5 blends. The WAXD diagrams are characterized by the six-point pattern consisting of an equatorial reflection at $2\theta = 12.2°$ and a diagonal reflection at $2\theta = 20.4°$, and are attributed to the mesomorphic phase of sPS. It was reported that the oriented mesophase was induced in stretched sPS films.[18,19] It is confirmed in this work that the mesophase is also formed in the drawn films of sPS/PPO blends with PPO content higher than 50%. Auriemma

et al. analyzed the mesomorphic form of sPS, through a simulation of X-ray diffraction intensity based on a model consisting of bundles of sPS chains with paracrystalline disorder.[21] It was shown from the result of calculation that the mesomorphic phase consisted of small and imperfect crystals of the α-crystalline form. The reflections are observed as sharp spots in the azimuthal direction, suggesting the high degree of orientation in the mesophase. However, the intensity of the reflections decreases and the intensity of amorphous scattering increases with increasing PPO content. Figure 2 shows the WAXD profile of a drawn sPS film that is obtained from the WAXD diagram by integrating the intensity in whole azimuthal directions. The observed WAXD profiles can be separated into contributions of amorphous scattering and mesophase scattering by subtracting amorphous scattering from the observed profile. Amorphous scattering was scaled so that the intensity of mesophase scattering falls to the noise level at $2\theta = 8–9.5°$ and $2\theta = 29–33°$. The mesophase content was obtained from the ratio of the integrated intensity of mesophase scattering to the intensity of the observed profile, and the result is shown in Figure 3. For pure sPS and sPS/PPO
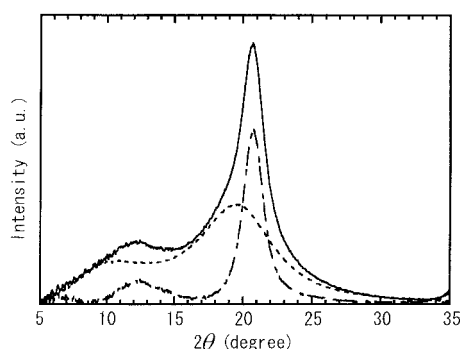

Figure 2 WAXD profile of drawn sPS: (—) observed profile; (- - -) amorphous contribution; (— - —) mesophase contribution.
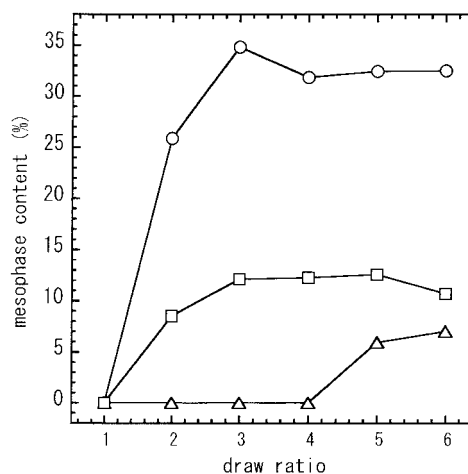

Figure 3 Mesophase content versus draw ratio: (○) sPS; (□) sPS/PPO = 7/3 blend; (△) sPS/PPO = 5/5 blend.

= 7/3 blend, the amount of mesophase increases with increasing draw ratio and becomes nearly constant above a draw ratio of 3. However, for the sPS/PPO = 5/5 blend, the mesophase is not induced at lower draw ratios but is formed for the sample with draw ratios higher than 4. The degree of orientation increases with increasing draw ratio, and the mutual orientation of molecular chains of sPS is considered to be responsible for the mesophase formation. The mesophase content markedly decreases with increasing PPO content under the same draw ratio. It is interpreted that the orientation of molecular chains of sPS partially relaxes because of the miscibility with PPO and that the relaxation lowers the stability of the mesophase.

Orientation functions

The oriented mesophase gives rise to a meridional reflection at $2\theta = 35.3°$, which corresponds to the 102 reflection of the α'- and α''-crystalline forms. A hexagonal unit cell with $a = 2.626$ nm and $c = 0.504$ nm is proposed for the α'- and α''-crystalline forms.[12,13] The peak position of the meridional reflection of the mesophase is nearly the same as that of the α'- and α''-crystalline forms, indicating that the conformation in the mesophase is a *trans*-zigzag form, the conformation of the α'- and α''-crystalline forms. The orientation functions of the mesophase can be obtained from the azimuthal intensity distribution of the meridional reflection. However, the tilting angle of the [102] axis from the chain-axis should be corrected, if the meridional reflection of mesophase corresponds to the 102 reflection of the α'- and α''-crystalline forms. The orientation function of the chain direction (crystal c-axis) f_c can be obtained from the azimuthal intensity distribution $I(\phi')$ of the meridional reflection at $2\theta = 35.3°$, after the off-meridional character of the [102] reflection was corrected according to the procedure proposed by Gupta and Kumar.[23]

$$\langle \cos^2 \phi' \rangle = \int_0^\pi I(\phi')\cos^2 \phi' \sin \phi' d\phi' / \int_0^\pi I(\phi')\sin \phi' d\phi'$$

$$\langle \cos^2 \phi \rangle = \langle \cos^2 \phi' \rangle / \cos^2 \gamma$$

$$f_c = (3\langle \cos^2 \phi \rangle - 1)/2 \tag{1}$$

where ϕ and ϕ' are the angles of the chain direction (c-axis) and the [102] axis, respectively, measured from the drawing direction, and γ is the angle between the chain axis and the [102] axis (5.57°). The values of f_c are presented in Figure 4. The orientation function is almost constant with the draw ratio for pure sPS and sPS/PPO blend, and very close to unity, suggesting
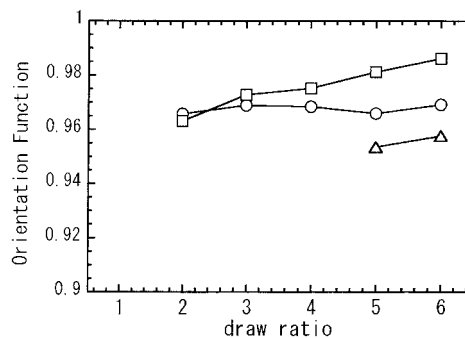

Figure 4 Orientation functions of mesophase versus draw ratio: (○) sPS; (□) sPS/PPO = 7/3 blend; (△) sPS/PPO = 5/5 blend.

the high degree of orientation of molecular chains in the mesophase.

Figure 5(a) shows the polarized FTIR spectra of a drawn film of sPS with a draw ratio of 6 in the wavenumber region of 400–1400 cm^{-1}. The FTIR spectra of sPS have been interpreted in relation to the conformation and structural order, and some of the absorption bands were successfully assigned to the α- and β-crystalline forms.[24] Some absorption peaks, which are absent in the spectrum of the amorphous sPS sample, are observed in the polarized spectra of oriented samples with large dichroism, for example, at 1156, 1222, and 1276 cm^{-1}. These absorption bands are attributed to the *trans*-zigzag conformation in the oriented mesophase. The polarized FTIR spectra of a drawn film of sPS/PPO = 7/3 blend are shown in Figure 5(b). PPO exhibits intense absorption bands with dichroism at 836, 858, 960, 1021, 1190, and 1305 cm^{-1}. The polarized FTIR spectra suggest that the molecular chains of both sPS and PPO are oriented in the drawing direction. The absorption bands of PPO overlap considerably with those of sPS, particularly in the wavenumber region of 1000–1400 cm^{-1}. In this work, the orientation functions of molecular chains of sPS and PPO were calculated from the dichroic ratio of the 903 and the 858 cm^{-1} bands, respectively, because these bands are well isolated from the other bands. The 903 cm^{-1} band is sensitive to the packing of the polymer chains of sPS and originates from both the amorphous phase and mesophase. The peak of the band is located at 905 cm^{-1} in the spectrum of amorphous samples, but shifts to 902 cm^{-1} in the α-crystalline form.[24] The 858 cm^{-1} band is assigned to the out-of-plane bending vibration of the 1,2,4,6-tetrasubstituted benzene ring of PPO.

Figure 6 shows the orientation function of molecular chains of sPS that is obtained from the dichroic ratio of the 903 cm^{-1} band. The orientation functions are expressed by
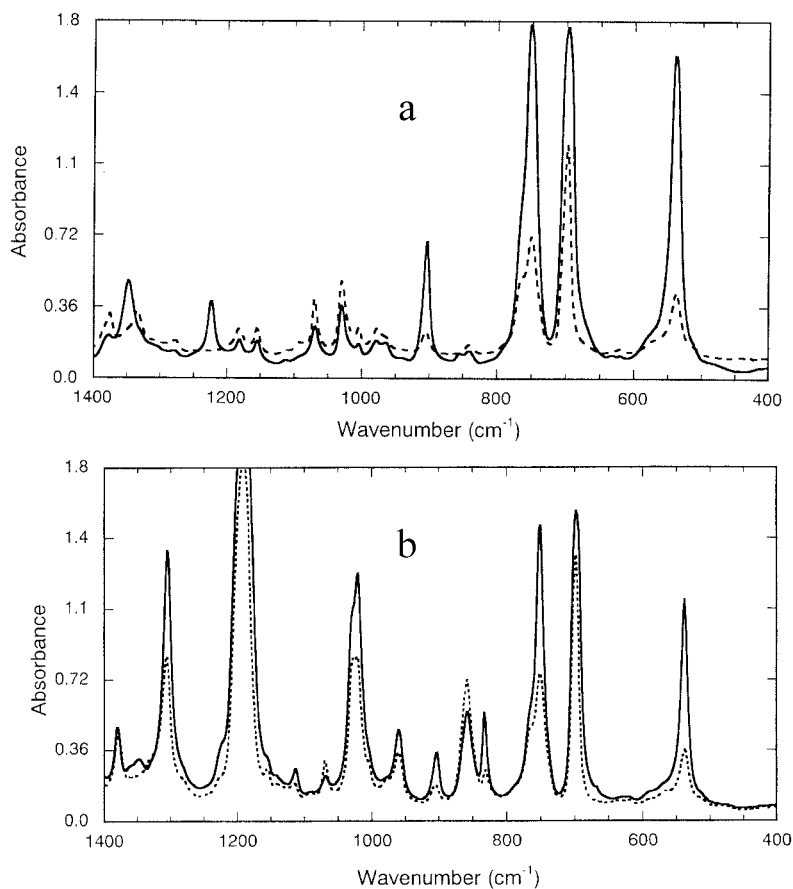
$$f = (D - 1)/(D + 2) \tag{2}$$

Figure 5 Polarized FTIR spectra of a drawn film of sPS with a draw ratio of 6 in the wavenumber region of 400–1400 cm^{-1}: (a) sPS; (b) sPS/PPO = 7/3; (—) parallel polarization; (- - -) perpendicular polarization.

where D is the dichroic ratio, calculated from the integrated intensity of absorption bands. Because the 903 cm^{-1} band originates from the molecular chains in the amorphous and crystalline phases, the orientation function in Figure 6 represents the averaged orientation of
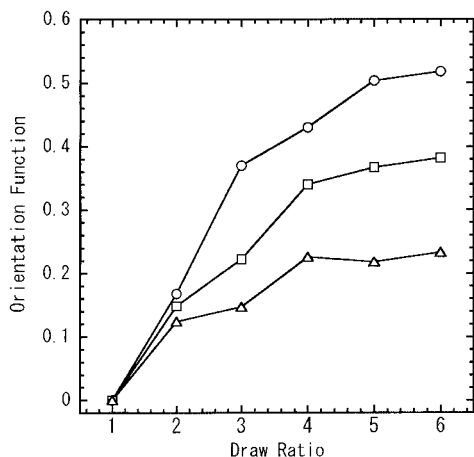
molecular chains in the amorphous phase and mesophase. The orientation function of molecular chains of sPS increases monotonically with increasing draw ratio. It is interpreted that the orientation function in the amorphous phase increases with increasing draw ratio because the orientation function in the mesophase is nearly constant over the draw ratio (Fig. 4). The orientation function decreases with increasing PPO content under the same draw ratio, suggesting that the molecular orientation of sPS chains is relaxed with the addition of the miscible amorphous component. Figure 7 shows the orientation functions of the amorphous chains of PPO, which were obtained from the dichroic ratio of the 858 cm^{-1} band. The orientation function decreases to a negative value with increasing orientation of molecular chains in the drawing direction because the transition moment vector of the band is perpendicular to the polymer chain axis. The degree of orientation of PPO chains increases with increasing draw ratio. The orientation function is higher for the sPS/PPO = 7/3 blend than that for the sPS/PPO = 5/5 blend under higher draw ratios, and the degree of orientation of PPO chains is relaxed with increasing PPO content similar to the molecular orientation of sPS chains.
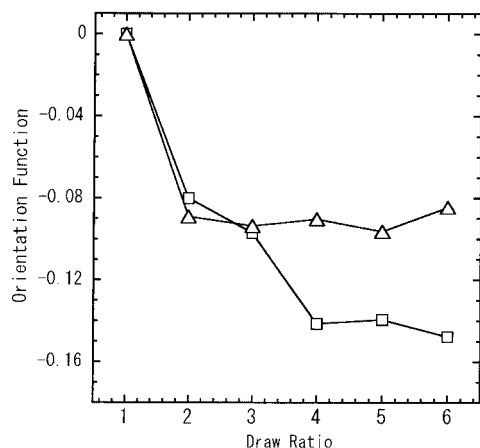

Figure 6 Orientation function of molecular chains of sPS obtained from the dichroic ratios of the 903 cm^{-1} band: (◯) sPS; (□) sPS/PPO = 7/3 blend; (△) sPS/PPO = 5/5 blend.

Figure 7 Orientation function of amorphous chains of PPO, obtained from the dichroic ratio of the 858 cm^{-1} band: (○) sPS; (□) sPS/PPO = 7/3 blend; (△) sPS/PPO = 5/5 blend.

Mechanical properties

Figure 8 shows the dynamic viscoelasticity of a drawn film of pure sPS with a draw ratio of 6 measured in the parallel and perpendicular directions. The dynamic loss modulus shows a peak at 90–100°C, and the dynamic storage modulus steeply decreases with tem-perature in this temperature range. This peak is as-signed to the glass transition because the peak tem-perature of dynamic loss modulus is close to the glass-transition temperature of sPS detected by differential scanning calorimetry. The dynamic storage modulus changes very gradually with temperature and the loss modulus does not show any peak below 70°C, sug-gesting that there is not any significant relaxation pro-cess below the glass transition. The dynamic storage modulus of pure sPS with draw ratio 6 is 7.7 GPa at room temperature and is nearly three times higher in the stretching direction than that in the perpendicular direction in the temperature range of −150 to 90°C. In the higher-temperature region (130–150°C), the dynamic storage moduli for the parallel and perpendicular direc-tions are 0.4 and 0.3 GPa, respectively. In the case of an amorphous film of sPS, the dynamic storage modulus is lower than 0.01 GPa in this temperature range. Thus the modulus in the higher-temperature region is signifi-cantly increased for the oriented sample both in the parallel and perpendicular directions, compared with the modulus of isotropic samples. This is because the oriented mesophase increases the mechanical properties of the materials and stabilizes the dimensions of the samples above the glass-transition temperature.
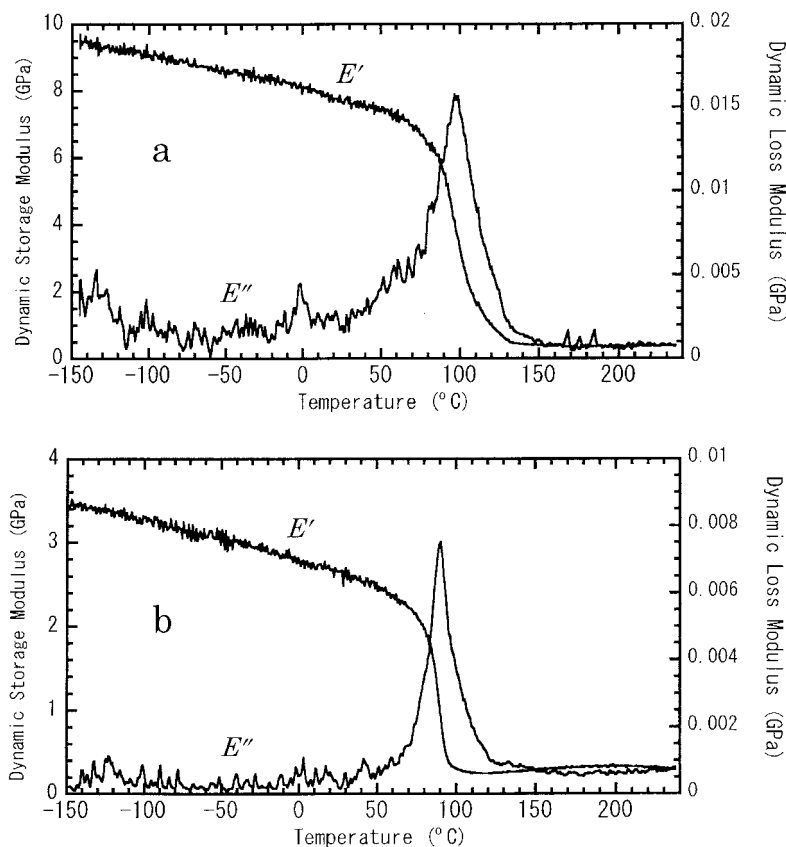

Figure 8 Dynamic viscoelasticity of a drawn film of sPS with a draw ratio of 6: (a) parallel to the drawing direction; (b) perpendicular to the drawing direction. E', dynamic storage modulus; E'', dynamic loss modulus.
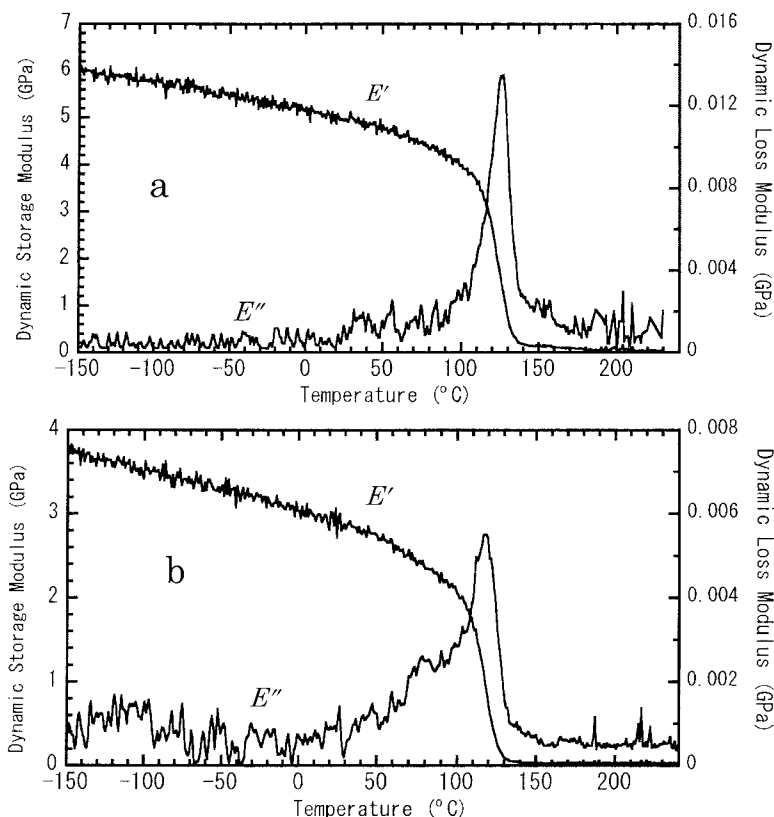
Figure 9 Dynamic viscoelasticity of a drawn film of sPS/PPO = 7/3 blend with a draw ratio of 6: (a) parallel to the drawing direction; (b) perpendicular to the drawing direction. E', dynamic storage modulus; E'', dynamic loss modulus.

Figure 9 shows the dynamic viscoelasticity of a drawn film of sPS/PPO blend with draw ratio 6. The peak of dynamic loss modulus shifts to 120–125°C for the sPS/PPO = 7/3 blend, given that the glass-transition temperature increases with increasing PPO content because of the miscibility of sPS and PPO.[15–17] The dynamic storage modulus of the oriented sPS/PPO = 7/3 blend is 4.7 GPa in the parallel direction at 20°C, and is lower than that for the oriented sPS (7.7 GPa). The decrease in modulus is related to the relaxation of molecular orientation and the decrease in mesophase content.

Figure 10 shows the stress–strain curves of a drawn film of pure sPS with a draw ratio of 6 tested in the parallel and perpendicular directions. When the testing direction is parallel to the drawing direction, the sample can be deformed to a strain of 0.12. The stress steeply increases with increasing strain in the range of lower strain (0.00–0.03), and the slope of the stress–strain curve becomes gradual in the strain range of 0.04–0.12. The ultimate strength (breaking strength) of the oriented sPS film in the parallel direction is 3.6 times higher than the strength of the isotropic sPS film (44 MPa). On the other hand, the strength is as low as 18 MPa in the direction perpendicular to the stretching. The drawn films of pure sPS are very brittle in the perpendicular direction and are easily fractured at low stress and low strain.

Figure 11 shows the stress–strain curves of a drawn film of sPS/PPO = 7/3 blend with a draw ratio of 6. The shape of the stress–strain curve for the oriented blend film is similar to that for the drawn film of pure sPS, when the specimen is tested in the parallel direction. The ultimate strength is a little lower for the former than for the latter, whereas the strain at break is higher for the former than for the latter. The marked
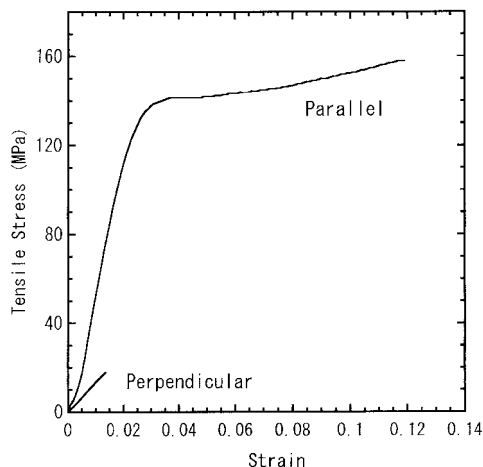

Figure 10 Stress–strain curves of a drawn film of sPS with a draw ratio of 6 tested in the parallel and perpendicular directions.
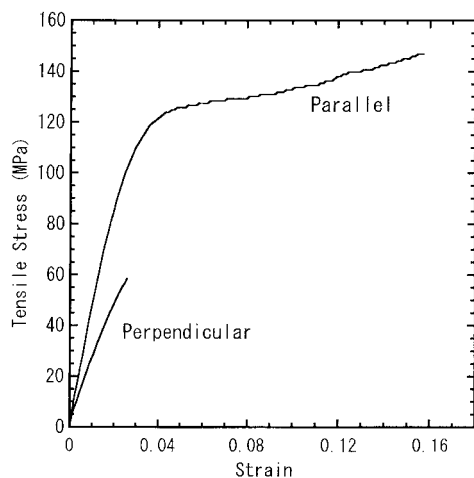
Figure 11 Stress–strain curves of a drawn film of sPS/PPO = 7/3 blend with a draw ratio of 6 tested in the parallel and perpendicular directions.

difference between the sPS/PPO = 7/3 blend and pure sPS was found in the stress–strain curve in the perpendicular direction. The ultimate strength in the perpendicular direction is much improved in the oriented sPS/PPO = 7/3 blend films and the value (58 MPa) is close to the strength of the isotropic sPS film.

The mechanical properties of sPS and sPS/PPO blend are summarized in Table I. The ultimate strength in the parallel direction increases and that in the perpendicular direction decreases with increasing draw ratio for the drawn films of sPS/PPO blends and pure sPS. The decrease in strength in the perpendicular direction is smaller for the sPS/PPO = 7/3 blend than for pure sPS. The dynamic storage modulus in the parallel direction also increases with increasing draw ratio, but the change in modulus is small for the perpendicular direction. The anisotropy in the mechanical properties is caused by the formation of oriented mesophase and the orientation of amorphous chains of PPO and sPS. For the isotropic samples (draw ratio = 1) of the sPS/PPO blend, the synergetic effects on the strength and modulus are clearly observed. The ultimate strength and the dynamic storage modulus of the sPS/PPO blends are higher than the weighted average of the mechanical properties of the pure polymers at the blend compositions. In particular, the ultimate strength of sPS/PPO blends are higher than the averaged strength of the pure polymers by a factor of 1.3–1.5 in the composition range of sPS/PPO = 7/3 to 3/7.

Structure–property relationship

The deformation and fracture behaviors of atactic polystyrene (aPS) and PPO blend system were previously investigated under various compositions.[25,26] The aPS/PPO blend deforms by crazing and finally fails by brittle fracture at low PPO content, whereas the blend fails by shear yielding in a ductile manner at high PPO ratios.[25] Blending a small amount of PPO with aPS significantly lowered the yield stress and elastic modulus of aPS, and the change in the yield behavior was related to the transition of the fracture mechanism.[26] The fracture behavior in the aPS/PPO blend system has been discussed in relation to the changes in the amorphous structures.[27,28] It was reported that the blending of PPO with aPS disrupts the microsegregation of the phenyl groups of pure aPS that may be responsible for the brittle behavior of aPS.[27] It was also reported that the mechanical behavior in the aPS/PPO system is related to the increase in entanglement density with increasing PPO content.[4,28] These structural changes in the amorphous phase of aPS/PPO blend are considered to be responsible for the synergetic effects on the ultimate strength in the isotropic film of the sPS/PPO blend system. The syn-

TABLE I
Mechanical Properties of Uniaxailly Drawn Films of sPS/PPO
Blend Measured at 20°C

sPS/PPO	Draw ratio	Ultimate strength (MPa)		Dynamic storage modulus (GPa)	
		Parallel	Perpendicular	Parallel	Perpendicular
10/0	1	44		2.79	
	3	74.8	38.0	3.67	2.73
	6	157	17.9	7.71	2.68
7/3	1	62.7		2.96	
	3	114	53.7	3.92	2.87
	6	146	58.3	4.68	2.90
5/5	1	75.2		2.73	
	3	121	45.7	3.61	2.80
	6	129	34.7	3.71	2.61
3/7	1	71.2		2.76	
0/10	1	55.0		2.26	

ergetic effects of the blend on the ultimate strength are considered to be one of the causes of the marked increase in the perpendicular strength of the sPS/PPO blend compared with that of the oriented pure sPS. Another factor that is important in determining the strength of materials is molecular orientation. The orientation of amorphous chains of PPO and sPS relaxes in the drawn film of sPS/PPO blend compared with the oriented sPS, as found by polarized FTIR spectroscopy. The relaxation of chain orientation suppresses the fibrillation of the materials and thereby improves the mechanical properties in the perpendicular direction.

CONCLUSIONS

Highly oriented mesophase was induced by drawing the amorphous films of sPS and sPS/PPO blends in the composition range of sPS/PPO = 10/0 to 5/5. The mesophase content increases with increasing draw ratio and becomes nearly constant at a draw ratio of more than 3. Under the same draw ratio, the mesophase content decreases with increasing PPO content. The mesophase is not induced for the drawn films of sPS/PPO = 5/5 blend with a draw ratio lower than 5. The orientation function in the mesophase is as high as 0.95–0.99 irrespective of the composition and draw ratio. On the other hand, the orientation functions obtained by polarized FTIR spectroscopy are sensitive to draw ratio and composition. It is considered that the orientation of molecular chains in the amorphous phase and mesophase increases with increasing draw ratio and decreases with increasing PPO content. The drawn films of pure sPS show high strength and high modulus in the drawing direction, but low strength in the direction perpendicular to the drawing. In the case of sPS/PPO = 7/3 blend, however, the ultimate strength in the perpendicular direction was markedly improved and the ultimate strength in the parallel direction was similar to that for the oriented pure sPS. The improved mechanical properties of the sPS/PPO blends were considered to relate to the relaxation of amorphous orientation and the synergetic effect that is specific to the sPS/PPO blend system.

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