

STUDIES ON PARTIAL COMPATIBILITY OF PP AND PS

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Abstract Blends of polystyrene (PS) and polypropylene (PP) were prepared through melt compounding. With an increase of PS content up to 30 wt%, the tensile strength of PP/PS blends increased from 37.4 MPa to 42.2 MPa, although the blends were widely regarded as immiscible. The DSC results showed that there's slight decrease in melting temperature of PP, showing insufficient evidence for partial compatibility between PP and PS. Almost no variation of distinct characterization peaks were observed in FTIR spectra of PS/PP blends compared with those of neat PP and PS, indicating there is no chemical interactions between PP and PS. Since the morphology investigation showed a droplet structure as PS content was up to 30 wt%, the improvement of tensile strength could be simply considered as due to the reinforcing effect of dispersed rigid PS particles on the PP, combining with partial compatibility between them as evaluated by change of C_p at glass transition for both PS and PP. More interestingly, DSC and DMA results showed that the blending of PS and PP could lead to a substantial decrease of the glass transition temperature (T_g) of PP, and increase of T_g of PS. The annealing experiment was carried out to understand the change of T_g in PP/PS blends. It is believed that the compressive stress generated by the contracting PP should be the dominant mechanism for the T_g elevation of PS. On the other hand, the T_g decrease of PP is likely owing to the creation of a large amount free interface of PP and the dilatation of the PP phase resulting from the corresponding tension exerted by PS during cooling.

Keywords: Polypropylene; Polystyrene; Tensile strength; Glass transition temperature; Compatibility; Interaction.

INTRODUCTION

Polymer blending is an effective way to combine the properties of individual components together. Polypropylene (PP) and polystyrene (PS) are two of the widely used plastics in the world, their blends have received important industrial interest. However, PP and PS are widely regarded as immiscible due to significant differences in solubility parameters. For a blend consisting of two immiscible polymers, there are two important factors that affect the mechanical properties of the blend: the morphology of the dispersed phase and the interfacial adhesion between the dispersed phase and the matrix^[1, 2]. Many researchers reported that the mechanical properties of PP/PS blends were poor^[3], because of the lack of interfacial adhesion between the components.

Thermal analysis has been used to study the compatibility of polymers in blends. The thermal behavior of the blends such as the glass transition temperature (T_g) and melting temperature (T_m) are of particular interest. Experimentally, compatibility in polymer blends is generally demonstrated by the observation of a single, composition-dependent glass transition temperature, while constant T_g of each component indicates a totally incompatible blends. The presence of two T_g s shifted toward each other indicates partial compatibility between components in the blends. Interesting glass transition phenomenon of PP and PS was observed in PP/PS blends.

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It's found that the T_g of PS in PP/PS blends get higher than that of PS in isolation. The T_g of PP phase shifted to lower temperature with increasing PS content. Thus it is logical to ask: are the blends of PP and PS really incompatible? At this moment it is still not well understood about the mechanisms of the interesting glass transition phenomenon. Greco and coworkers suggested that a selective extraction of low molecular weight PS fractions into the polyolefin phase took place and that the higher observed glass transition temperature reflects the effect of the higher molecular weight residual PS phase^[4]. Moreover, Mucha attributed this observation to the suppression of segmental motions of PS by the presence of PP crystallites and the specific interaction between them^[5]. Thirtha suggested that compressive stress generated by the contracting polypropylene matrix appeared to be the dominant mechanism in raising polystyrene T_g ^[6]. He also ascribed the elevation of T_g to some type of composite interaction in his later paper^[7]. However, he had not given the experiment evidence for explaining the contraction mechanism and the interaction mechanism for the T_g elevation of PS. Few papers have been reported about the changes of T_g of PP, and some researchers ascribed it to the mismatch of thermal expansion coefficients between the two components^[8].

In the present study, the relationships between phase morphology and mechanical properties of the PP/PS blends were investigated in detail. It was found that with an increase of PS content up to 30 wt%, the tensile strength of PP/PS blends is increased from 37.4 MPa to 42.2 MPa, although the blends are widely regarded as completely incompatible. On the other hand, DSC and DMA results showed that the blending of PS resulted in a substantial decrease of the glass transition temperature (T_g) of PP, and an increase of glass transition temperature (T_g) of the PS although they are completely incompatible. FTIR, SEM and annealing experiments were carried out to understand the interesting enhancement of tensile strength and changes of glass transition temperatures for this incompatible polymer blend.

EXPERIMENTAL

Materials

The materials used for preparation of PP/PS blends are listed in Table 1. The PP and PS used in the experiment are commercial products, PP (T30S, melt flow index is 3.0 g/10min) and PS (PG33, melt flow index is 8.0 g/10min) were purchased from the Du Shanzi Petroleum Chemical and Chi Mei Petroleum Chemical, China.

Table 1. Materials

Materials	Brand	$M_n \times 10^{-4}$	Supplier	Characteristics
iPP	T30s	28	Du Shan Zi Petroleum Chemical, China	MFI = 2.64 g/10min (210°C, 2.16 kg)
PS	PG33	8	Chi Mei Petroleum Chemical, China.	MFI = 8.0 g/10min (200°C, 5 kg)

Sample Preparation

The blending was conducted in a two-screw extruder at 150–210°C, and then injection molded in a PS40E5ASE (Japan) injection-molding machine at 180–210°C to obtain standard specimens for mechanical property tests. The blend compositions with their sample codes are listed in Table 2.

Table 2. Sample code and composition of the blends in present study

Composition	Sample code						
	S1	S2	S3	S5	S7	S8	S9
PP/PS	90/10	80/20	70/30	50/50	30/70	20/80	10/90

Tensile Strength Tests

An instron universal testing machine was used to measure the tensile strength with a crosshead speed of 50 mm/min and a measuring temperature of 23°C. The values of all the mechanical parameters were calculated as averages over 5 samples for each composition.

Scanning Electron Microscopy (SEM)

A JEOL JSM-5900LV SEM instrument was used to examine the morphology of the fractured surfaces and the dispersed particles in the matrix using an acceleration voltage of 20 kV. The samples were fractured in the direction perpendicular or parallel to the flow direction in liquid nitrogen or achieved after impact test. The fractured surfaces of the specimens were sputter coated with a thin gold layer prior SEM examination.

FTIR Measurements

The samples were prepared by compression using the extrusion pellets. The spectra were recorded on a Nicolet 560 MAGNA IR spectrometer in a range from 600 cm^{-1} to 3500 cm^{-1} .

Differential Scanning Calorimetry (DSC)

The crystallization and melting behavior of the samples were determined by differential scanning calorimetry (DSC) with a Perkin–Elmer DSC Priys-1 in a nitrogen atmosphere. The samples were preheated quickly from room temperature to 200°C , held at that temperature for 5 min to eliminate the thermal history, cooled from 210°C to 30°C at a rate of 10 K/min, and finally reheated again to 200°C at the same rate. The crystallization and melting parameters were recorded from the cooling and reheating scans. The glass temperatures were measured also by DSC experiments, the samples are cooled more slowly (10 K/min) than they are heated (100 K/min).

Dynamic Mechanical Analysis (DMA)

The dynamic mechanical analysis was carried out using a TA Instruments Q800 DMA. All the samples were measured in a dual cantilever mode over the temperature range of -40°C to 100°C at a heating rate of 3 K/min and at a frequency of 10 Hz. Specimen dimensions were $40\text{ mm} \times 10\text{ mm} \times 4.2\text{ mm}$.

RESULTS AND DISCUSSION

Mechanical Properties

The tensile strength and tensile modulus of PP/PS blends as the function of PS content are shown in Fig. 1, one observes a gradual increase of tensile modulus as increasing the PS content. The tensile strength increases as increasing of PS content up to 30 wt%, where a maximum is seen. Then the tensile strength decreases to a minimum value when the PS content up to 70 wt%, following with an increase again with further increasing of PS content.

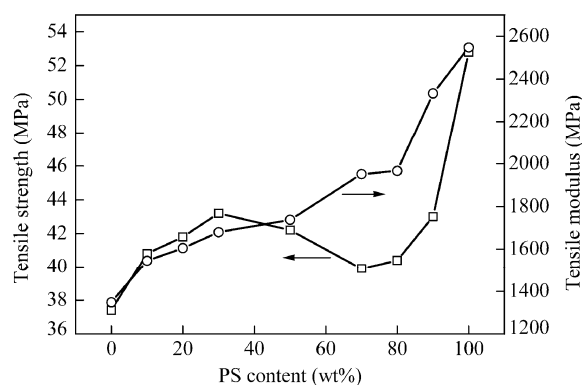


Fig. 1 The tensile strength and tensile modulus of PP/PS blends as the function of PS content

Crystallization and Melting Behavior of PP

The DSC experiments were carried out to study the melting and crystallization behavior of PP/PS blends. Figure 2 depicts the DSC melting curves of the samples. DSC measurements indicate that the melting temperature of PP has a slight decrease with increasing PS content. Figure 3 shows the DSC cooling curves at 10 K/min of the PP/PS blends. A dominant crystallization peak at about 116°C is observed in the blends when PS content is in the range of 10 wt%–70 wt%. At the composition PP/PS 20/80, the PP crystallizes in a

fractionated fashion at temperatures 114°C and 75°C. The peak at 114°C is attributed to the bulk crystallization of PP, whereas the second peak at 75°C is due to homogenous nucleation of the PP droplets. The PP also crystallizes homogeneously at 72°C in PP/PS 10/90 blends. In PP/PS 10/90 blends, PP is finely dispersed in PS matrix with the droplet size of approximately 0.5–2 μm (see Fig. 5e), the PP crystallizes *via* homogeneous nucleation. Crystalline polymers in the bulk usually nucleate on existing heterogeneities. However, if the bulk polymer is subdivided into isolated regions whose number is significantly greater than the number of usually active heterogeneities, it will crystallize at a homogeneous crystallization temperature, then a fractionated crystallization phenomenon occurs^[9, 10]. The isolation of small polypropylene domains in polystyrene at low polypropylene concentrations results in a transition to homogeneous nucleation with a concomitant decrease in crystallization temperatures.

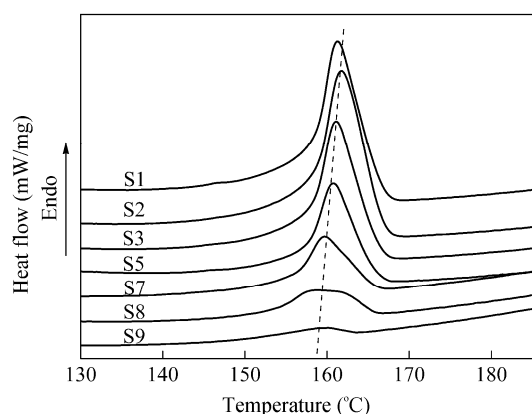


Fig. 2 DSC heating curves for PP/PS blends

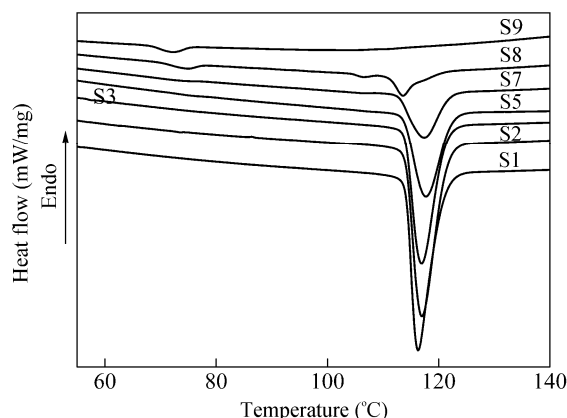


Fig. 3 DSC cooling curves for PP/PS blends

FTIR Results

We have carried out FTIR experiments for the samples of PP, PS, PP/PS 90/10 and PP/PS 70/30 binary blends to verify the possible interactions between PP and PS, and the results are shown in Fig. 4. The stretching vibration peaks of CH_2 (2919 and 2839 cm^{-1}) and CH_3 (2950, 2867 cm^{-1}) of PP do not change with addition of 10 wt% and 30 wt% PS. The stretching vibration peaks of CH_2 (2919, 2849 cm^{-1}) of PS are overlapped with the peaks of PP. The stretching vibration peaks of $\text{C}=\text{C}$ of phenyl ring (1601, 1493, 1451 cm^{-1}) and the distortion peak of $\text{C}-\text{H}$ of phenyl ring (756 cm^{-1}) remain the same in PP/PS blends with addition of 10 wt% or 30 wt% PS compared to the neat PS. Thus no evidence of interaction between PP and PS is observed.

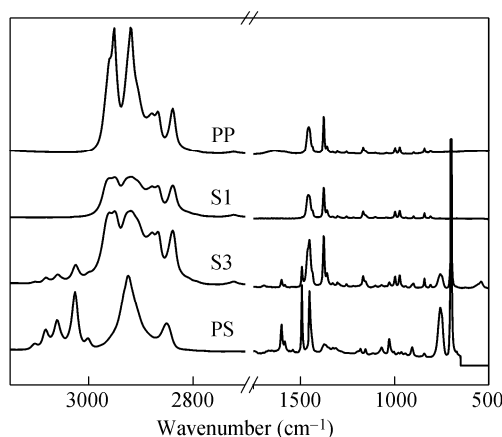


Fig. 4 FTIR spectra of PP, PS and PP/PS (90/10, 70/30) blends

Phase Morphology

Figure 5 demonstrates a two-phase morphology from all the composition range. One observes a sea-island structure in the composition from 10 wt% to 30 wt% PS content, which indicates that PS forms a dispersed phase and PP forms a continuous phase in these composition regions (Figs. 5a, 5b). PS particles are well dispersed in PP matrix with micron particle size at 10 wt% PS content. Several PS particles deform into irregular shapes at 30 wt% PS content (Fig. 5b), where a maximum value of tensile strength is seen. The blends show the phase inversion at a wide region around 50 wt%–70 wt% PS (Figs. 5c, 5d). When the weight percents of PP and PS are equal, the co-continuous morphology starts to be observed in this composition (Fig. 5c), which is an intermediate state formed in the morphology transition from sea-island to completely co-continuous. When PS content is 70 wt%, a completely co-continuous morphology is seen, where the minimum tensile strength is observed in this composition. The sea-island morphology is seen clearly at 90 wt% PS content and the PP particles are finely dispersed in the PS matrix (Fig. 5e).

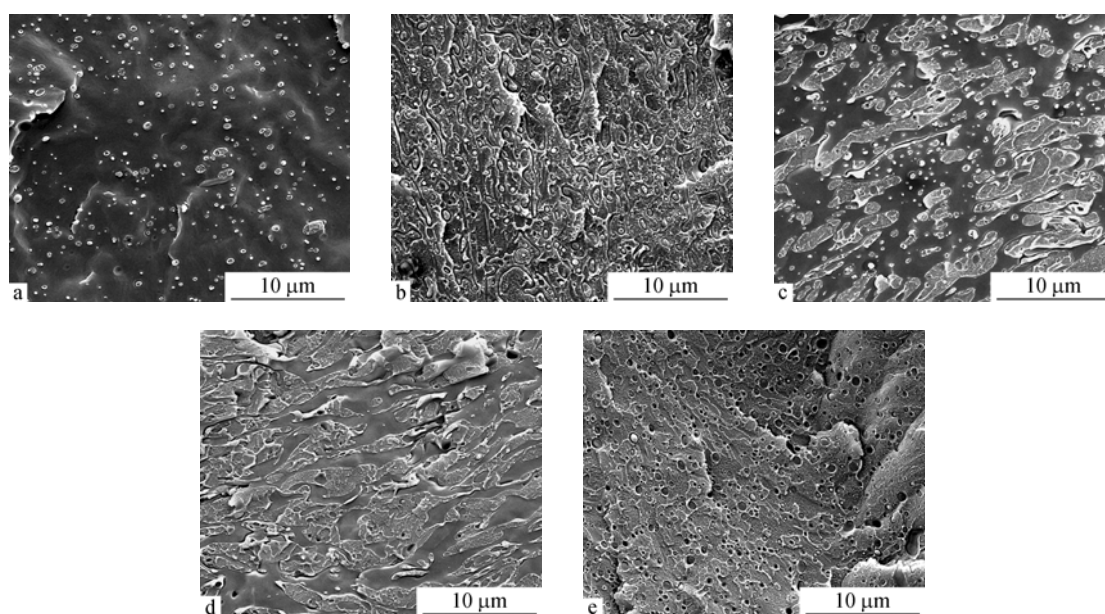


Fig. 5 SEM photographs of PP/PS blends
PP/PS: a) 90/10; b) 70/30; c) 50/50; d) 30/70; e) 10/90

Glass Transition Temperatures of PP and PS

The glass transition temperatures of PP and PS for various blend compositions were determined by DSC and DMA, respectively. The dynamic mechanical properties are investigated for PP/PS blends over the whole composition range. The changes in the mechanical loss factor with temperature for the PP/PS blends are shown in Fig. 6. The mechanical loss factor of the PP/PS blends shows two transitions at 10°C and 105°C corresponding to the T_g s of PP and PS phases, respectively, and gradual decreases between the transitions. In DSC experiments, the samples are cooled more slowly (10 K/min) than they are heated (100 K/min) to create hysteresis for better determining the glass transition temperature^[11]. Figure 7 shows the DSC traces of PP/PS blends containing different amounts of PS.

Apparently, the T_g s of PP and PS from both DMA and DSC depend strongly on the blend composition. The T_g of PS increases with increasing of PP content, which reaches the highest T_g value in the lowest PS content. DMA results also show that the incorporation of PP could lead to a substantial increase of the T_g of PS. Meanwhile, the T_g of the PP phase shifts to lower temperature as the PS content increases in PP/PS binary blends. The T_g for PP tested by DSC also shows the trend to decrease with increasing the content of PS. However, the signal of T_g for crystallized PP is so weak that T_g can not be detected by DSC when the content of

PP decreased (lower than 70 wt%). The T_g for neat PS is found to be 103°C from DSC result, which is lower than the temperature 105°C from DMA result. The glass temperature tested by DSC is usually higher than that by DMA experiment for different testing conditions.

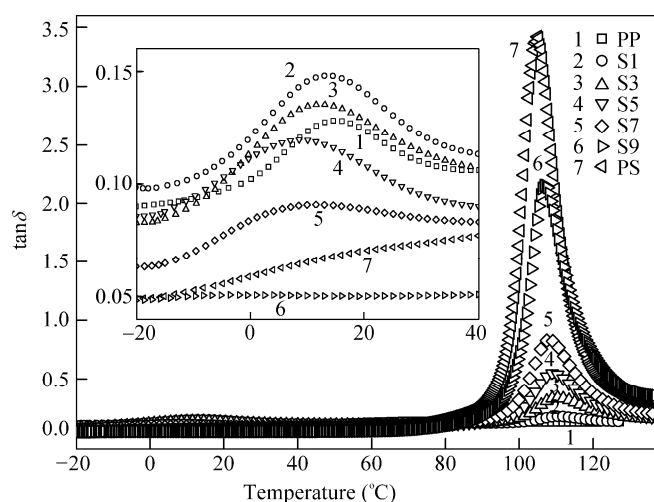


Fig. 6 Mechanical loss factor curves of DMA for PP/PS blends

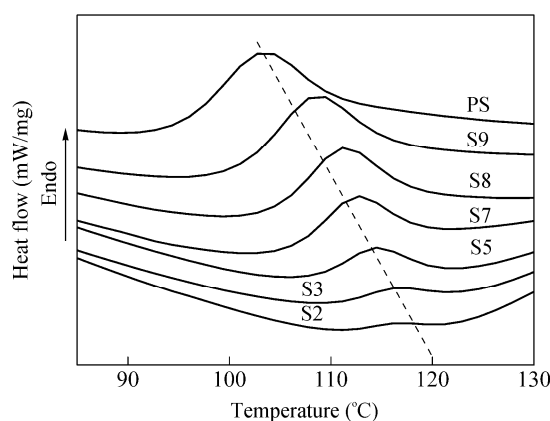


Fig. 7 DSC heat curves for PP/PS blends near the T_g of PS

The Enhancement of Mechanical Properties

The variation of mechanical properties has been used to characterize the level of compatibility in polymer blends. The mechanical properties of PP/PS blends are usually found worse than those of their component polymers because of the lack of interfacial adhesion between the components^[3]. However, PP/PS blends in our study exhibit a substantial increase in tensile strength at minor PS content. Mucha also saw a significant increase in the tensile strength of PP/PS films^[5]. He attributed this to the specific interactions between the molecules of the constituent polymers at the interface, resulting in the partial compatibility of PP and PS.

DSC measurements indicate that the melting temperature of PP has a slight decrease with increasing PS content. Observation of a melting temperature depression for the highest melting component in the blend is viewed as a good indication of compatibility^[12]. Mucha attributed the decrease in the melting temperature of PP to a certain degree of interactions between the two components. However, the slight decrease of melting temperature of PP provides an insufficient evidence of partial compatibility between the PP and PS phases. The specific interactions and the compatibility between polymer blends were thus assessed by FTIR because these

features may affect local electron densities and result in frequency shifts^[13, 14]. No variation of distinct characterization peaks is observed in FTIR spectra of PS/PP blends compared with those of neat PP and PS, indicating there is no specific chemical interaction between PP and PS. Thus one should consider other reason for the enhanced mechanical properties of PP/PS blends.

The change of C_p at glass transition, ΔC_p , is related to the interface content of a blend as a quantitative measurement for the compatibility of blends. As it is known that, for a fully phase-separated blend, the ΔC_p value of one component must be exactly the product of that in its pure state multiplied by its weight fraction in the blend, *i.e.* $\Delta C_p = \omega \Delta C_p^0$, where ΔC_p and ΔC_p^0 are heat capacity increasements in the blend and pure state, respectively and ω is the weight fraction of the component in the blend. Obviously, for a compatibilized blend, ΔC_p should be less than $\omega \Delta C_p^0$. The loss of ΔC_p between them means a reduction of the net amount of the component in the blend, indicating the mixed portion forming the interfaces in blends^[15, 16]. The ΔC_p of PP and PS at glass transition are listed in Table 3. For pure PS and PP, the values of ΔC_p^0 are 0.42 and 0.06 J/(g·°C), respectively. Theoretically, for a totally phase separated blends, the ΔC_p of PS should be the weight percentage multiplying 0.42, and $\omega \Delta C_p^0$ of PS should be 0.38, 0.34, 0.30, 0.21, 0.13, 0.04 for S9, S8, S7, S5, S3 and S1. As the same as PS, $\omega \Delta C_p^0$ of PP should be 0.056 and 0.043 for S1 and S3, respectively. As shown in Table 3, experimental values of ΔC_p for PP and PS are lower than the theoretical values ($\omega \Delta C_p^0$) of totally separated blends. Kang and Fried^[17, 18] reported the similar results, and they attributed this behavior to the presence of a large amount of materials in interfacial regions. Therefore, it is assumed that the loss of ΔC_p can be attributed to the mixed PP and PS portion in the interface of blends. Noticeably, PP shows obvious decrease in ΔC_p at glass transition, while PS shows slight decrease. On the other hand, this specific interaction between PS and PP could also result in free volume changes in the region of interface of crystalline and amorphous PP. This will lead to additional decrease of ΔC_p for PP component. Such it is reasonably to believe that interaction between PS and PP contributes to the partial compatibility and the improvement of tensile properties.

Table 3. ΔC_p of PS and PP at glass transition as a function of composition of PP/PS blends

ΔC_p (J/(g·°C))		Sample code					
		S1	S3	S5	S7	S8	S9
PS	$\omega \Delta C_p^0$	0.04	0.13	0.21	0.30	0.34	0.38
$\Delta C_p^0 = 0.42$	ΔC_p	—	0.12	0.21	0.26	0.32	0.34
PP	$\omega \Delta C_p^0$	0.06	0.04	0.03	0.02	0.01	0.01
$\Delta C_p^0 = 0.06$	ΔC_p	0.02	0.02	—	—	—	—

* The values of ΔC_p^0 (J/(g·°C)) for pure PS and PP were experimental values obtained from DSC curves at glass transition.

On the other hand, the morphology of the PS phase will also influence the tensile properties of PP/PS blends. Even though there is lack of chemical interaction between PP and PS, the fine submicron scale particle size in sea-island morphology is capable of affecting the mechanical properties. As can be seen, the tensile strength increases with increasing PS content when PS is the dispersed phase in PP matrix. The droplet morphology contributes to the enhanced tensile strength with the PS content from 10 wt% to 30 wt%. With the development of the phase morphology from droplet to co-continuous, the tensile strength decreases with increasing degree of co-continuity, which reaches the lowest tensile strength when there forms completely co-continuous morphology. Thus the variation of the tensile strength could be well related to the development of the phase morphology. It can be concluded that the improvement of tensile strength may also result from the reinforcing effect of dispersed rigid PS particles, as well as partial compatibility between PP and PS phases.

Interesting Changes of T_g of both PS and PP

PP/PS blends are widely regarded as incompatible and no shift of the glass transition temperature is expected in the incompatible polymer blends. However, both DMA and DSC demonstrate an interesting change of T_g s in PP/PS blends. That is: T_g of PS increases while T_g of PP decreases. In order to have a clear knowledge of the changes in T_g s of PP and PS, glass transition temperatures versus PS content are plotted in Fig. 8. The T_g s of PP and PS are measured by the peaks of the mechanical loss factor in DMA experiment. It should be noted that T_g of PS, PP can be measured *via* both DMA and DSC.

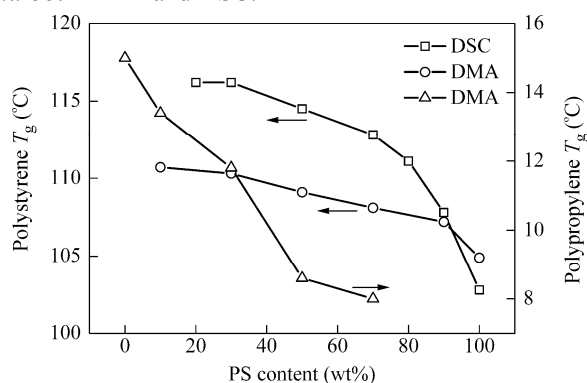


Fig. 8 PS and PP T_g as a function of composition in PP/PS blends

The T_g of a polymer material is related with the segmental motion of the polymer chains. The reasons for the variations of glass transition are still not well understood. Some authors ascribe it to the specific interactions between PP and PS. Thus we carried out DSC and DMA experiments with PP/PS 50/50 blends annealed at 155°C for two hours to further investigate the mechanisms of the T_g variations.

Figure 9 shows the melting curves of PP/PS 50/50 blends after annealing at 155°C for two hours. As can be seen, the melting temperature of PP shifts to higher temperature for the annealed blends, showing there forms more perfect PP crystals during annealing. Additionally, the crystallinity of PP in the annealed blends greatly increases. The T_g s of PP and PS in the annealed blends are measured by the peaks of the mechanical loss factor in DMA experiment, showing that both the T_g s of PP and PS in the annealed blends shift to higher temperatures. The T_g of PS increases from 109°C to 111°C, and the T_g of PP is increased from 8.5°C to 12.4°C after annealing. As we know, the recrystallization of PP during annealing process will further induce the phase separation and lead to poorer interfacial adhesion between PP and PS. Suppose the T_g elevation of PS is resulting from the specific interactions between PP and PS, the T_g of PS will restore to its original value or decrease in the annealed blends. However, the T_g of PS increases after annealed at 155°C, showing the T_g elevation of PS is not resulted from the interactions between PP and PS.

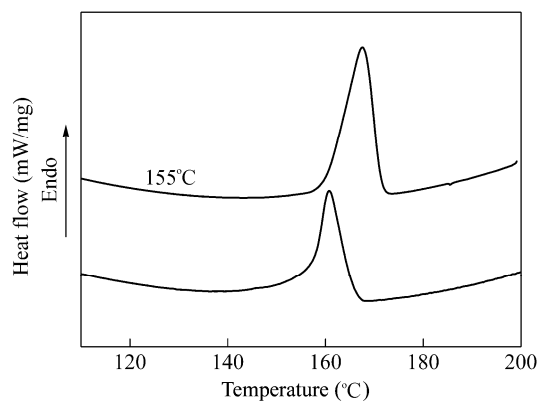


Fig. 9 The melting curves of PP/PS 50/50 blends after annealing at 155°C

The highest T_g is observed in the PP/PS 90/10 blends, in which composition the PS is completely surrounded by PP. The crystallization temperature of PP is higher than the glass transition temperature of PS, the PS will be under compressive stress to resist the PP contraction in the process of its crystallization, which will lead to the T_g elevation of PS. The blend morphology changes from dispersed to co-continuous as the PS content increases from 50 wt% to 70 wt%. For co-continuous morphology both phases surround each other and both phases are continuous. When the surface of PS is concave, the PP contracts away from the PS under cooling to become a non-contacting interface or exerts tension on the PS. When the surface of PS is protuberant, the PS will be surrounded by PP and under compressive stress as discussed above for systems of dispersed PS in PP. The further positive shift of T_g of PS in the annealed PP/PS 50/50 blends is attributed to the increasing compressive stress exerted to PS in the process of recrystallization, which is also an experimental evidence for this mechanism. In conclusion, the compressive stress generated by the contracting PP should be the dominant mechanism when PS is the dispersed phase or in the co-continuous morphology. The schematic drawing is shown in Fig. 10.

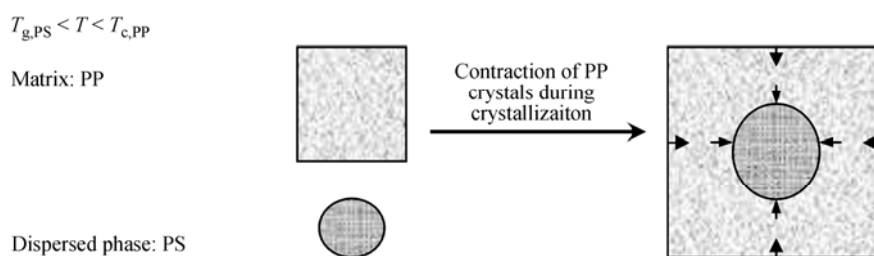


Fig. 10 The schematic drawing of mechanism of T_g elevation of PS in PP/PS blends when PS is the dispersed phase or in the co-continuous morphology

An increase in the glass transition of polymers melt blended with micron scale inorganic fillers has been observed by several investigators, and was attributed to the creation of an immobilized interfacial layer starting at the inorganic filler surface and extending a certain distance into the matrix^[19]. Thus, for blends with PS as the matrix, the presence of a solid immobile interface of PP in contact with PS during the glass transition process could also constrains the segmental motion of the PS chains during cooling and prevents conformation to low free volume configurations, resulting in elevated glass transition, which is similar to that observed in inorganic filled composite systems.

On the other hand, little attention has been paid to the thermal property of the PP phase in PP/PS blends. Pronounced reductions in T_g have been observed in systems filled with nanometer sized particles, due to the large amount of new surface area created by these particles in the polymer matrix^[20]. The decrease of T_g of the soft rubber was also observed in several plastic/rubber blends^[21–23]. The decrease of the T_g of the soft rubber phase is explained in terms of the negative pressure resulting from different thermal contraction between the soft phase and hard plastics, which results in the volume dilation of the rubber due to the thermal stress induced in the process of cooling from the melt. Starting from the glass transition temperature of PS, PP tends to shrink more strongly than PS phase. This difference in volume contraction can lead to a large amount of free-bonded interfaces in the incompatible blends. Particularly, when PP is finely dispersed in PS matrix in uncompatibilized PP/PS blends, usually at the micron scale, a significant amount of non-bonded interface is created. The non-bonded free interface can increase the segmental mobility of PP at the air/PP interface, through which the glass transition temperature of PP decreased. Moreover, starting from the glass transition temperature of PS, a part of PP shrinks away from the PS upon cooling and exerts tension on the PS. The PP phase will be forced to occupy a larger volume than the bulk PP by the corresponding tension exerted by PS; especially at the systems that PP is finely dispersed in the PS matrix, which will also lead to the dilatation of the PP phase. This may be another reason for the decrease of T_g of PP.

It's found that partial crystallization of *i*PS causes the increase of the T_g temperature of its amorphous

regions, which is due to the stiffening of polystyrene chains by the presence of crystallization of *i*PS^[24]. The T_g of PP shifts to higher temperatures after annealed at 155°C for two hours. The further T_g elevation of PP in annealed blends is likely due to the stiffening of PP chains by the more perfect PP crystals and increasing crystallinity induced by the recrystallization during annealing.

CONCLUSIONS

The blends of PS and PP are phase incompatible, and improvement of tensile strength of PP is observed as PS content up to 30%, where a droplets morphology is formed. Although almost no variation of distinct characterization peaks were observed in FTIR spectra of PS/PP blends compared with those of neat PP and PS, indicating no specific chemical interactions between PP and PS, analysis for the change of heat capability *via* DSC has indicated the specific interaction between PP and PS, which contributes to the improvements of tensile strength as well as reinforcing effect of dispersed rigid PS particles. The incorporation of PS could lead to a substantial decrease of the glass transition temperature (T_g) of PP. Meanwhile, the glass transition temperature (T_g) of the PS phase shifted to higher temperature as the PP content increases. It is shown in the DMA results of the annealed blend that the compressive stress generated by the contracting PP should be the dominant mechanism when PS is the dispersed phase or in the co-continuous morphology. The decrease of T_g of PP is likely owing to the creation of a large amount free interface of PP and the dilatation of the PP phase induced by the corresponding tension exerted by PS during cooling.

REFERENCES

- 1 Wu, S. *Polymer*, 1985, 26: 1855
- 2 D'Orazio, L., Greco, R. and Mancarella, C., *Polym. Eng. Sci.*, 1982, 22: 536
- 3 Wang, Y., Xiao, Y., Zhang, Q., Gao, X. and Fu, Q., *Polymer*, 2003, 44: 1469
- 4 Greco, R., Hopfenberg, H.B., Martuscelli, E., Ragosta, G. and Demma, G., *Polym. Eng. Sci.*, 1978, 18: 654
- 5 Mucha, M., *Colloid & Polymer Science*, 1986, 264: 859
- 6 Thirtha, V., Lehman, R. and Nosker, T., *Polym. Eng. Sci.*, 2005, 45: 1187
- 7 Thirtha, V., Lehman, R. and Nosker, T., *Polymer*, 2006, 47: 5392
- 8 Lee, S., Lee, J.H., Choi, K. and Rhee, J.M., *Polym. Bull*, 1998, 40: 765
- 9 Uriguen, J.I., Bremer, L., Mathot, V. and Groeninckx, G., *Polymer*, 2004, 45: 5961
- 10 Arnal, M.L. and Müller, A., *J. Macromol. Chem. Phys.*, 1999, 200: 2559
- 11 Liao, Y., *J. Mater. Sci. Lett.*, 1991, 10: 706
- 12 Cham, P.M., Lee, T.H. and Marand, H., *Macromolecules*, 1994, 27: 4263
- 13 Huang, C., Kuo, S., Lin, F., Huang, W., Wang, C., Chen, W. and Chang, F., *Macromolecules*, 2006, 39: 300
- 14 Cruz, D.M.G., Coutinho, D.F., Mano, J.F., Ribelles, J.L.G. and Sánchez, M.S., *Polymer*, 2009, 50: 2058
- 15 Song, M., Hammiche, A., Pollock, H.M., Hourston, D.J. and Reading, M., *Polymer*, 1995, 36: 3313
- 16 Pan, Y.X., Jia, D.M., Hu, H.J., Houston, D.J. and Song, M., *Polymer*, 2000, 41: 357
- 17 Kang, H.S., MacKnight, W.J. and Karase, F.E., *Polym. Pre.*, 1987, 28: 134
- 18 Fried, J.R. Thesis, University of Massachusetts, 1997
- 19 Huang, L., *J. Appl. Polym. Sci.*, 2004, 94: 1885
- 20 Ash, B.J., Schadler, L.S. and Siegel, R.W., *Mater Lett.*, 2002, 55: 83
- 21 Mader, D., Bruch, M., Maier, R., Stricker, F. and Mulhaupt, R., *Macromolecules*, 1999, 32: 1252
- 22 Bates, F.S., Cohen, R.E. and Argon, A.S., *Macromolecules*, 1983, 16: 1108
- 23 Tucker, P.S., Barlow, J.W. and Paul, D.R., *Macromolecules*, 1988, 21: 1678
- 24 Illers, K., *Colloid Z.*, 1969, 231: 622