

Polypropylene/Poly(Vinyl Acetate) Blend Fiber

WEIWEI XIAO

Polymer Research Institute, Chengdu University of Science & Technology, Chengdu, Sichuan, People's Republic of China

SYNOPSIS

Polypropylene/poly(vinyl acetate) (PP/PVAc) (30/70) blend possesses higher thermal stability than PVAc and is stable below 300°C. The viscosity of the blend is lower than that of PP and PVAc at 220°C. The blend fibers have sheath-core morphology; the core is composed of PP fibrils because PP has reasonably higher viscosity than PVAc. Due to the reinforcement of PP fibrils, the tensile strength and modulus of the blend fibers were increased. The blend fibers drawn at 50°C possess better mechanical properties than those drawn at 90°C. © 1994 John Wiley & Sons, Inc.

INTRODUCTION

The manufacturing of polymer blend fiber is very important in the modifications of fibers with respect to their mechanical, dyeing, hydrophilic, antistatic, thermal, and surface properties,¹ and is also one of the major production methods of ultrafine fibers applied in synthetic paper, artificial suede, reinforced film, nonwoven fabrics, sound-proof and heat-insulated materials, and so on. Therefore, in recent years, the research of various polyblend fibers is being progressively developed due to the extension of their applications as mentioned above.

In nonwoven fabric production, the heat-bonding fiber as a bonding material possesses evident advantages over the solution or latex adhesives. The widely used heat-bonding fibers include single-component fibers and sheath-core type complex fibers. It is difficult for a single-component heat-bonding fiber to provide sufficient bonding strength and to maintain fibrous shape simultaneously. A sheath-core bonding fiber, for example, the well-known ES fiber (PP/PE sheath-core fiber), has the disadvantage of production process complexity. According to this author's opinion, because of the differences of com-

ponents in rheological behavior, it is possible to prepare a blend fiber with disperse phase fibrils as core and this type of fiber would form firm bonding points and preserve fibrous shape in bonding nonwoven materials, but its manufacturing process is relatively simple. We have investigated poly(ethylene terephthalate)/polyethylene (PET/PE) blend heat-bonding fiber with the mentioned structure.² The present work is intended to report our study of polypropylene/poly(vinyl acetate) (PP/PVAc) blend fiber with the aim of its application in nonwoven fabrics as a heat-bonding fiber. As is well known, PVAc has very good adhesive properties for both polar and nonpolar polymers, but it has lower strength and lower softening point. By incorporating PP fibrils into the PVAc matrix, it would be reinforced and more heat-resistant and have improved spinnability.

EXPERIMENTAL

Materials

PVAc was supplied in a form of solution in methyl alcohol; its number-average molecular weight $\bar{M}_n = 1.02 \times 10^5$. PP resin is a powdery product with a melt flow index (MFI) of 2.1. Dye used for characterization of the sheath-core structure of the blend fibers is a disperse Blue 2NBL.

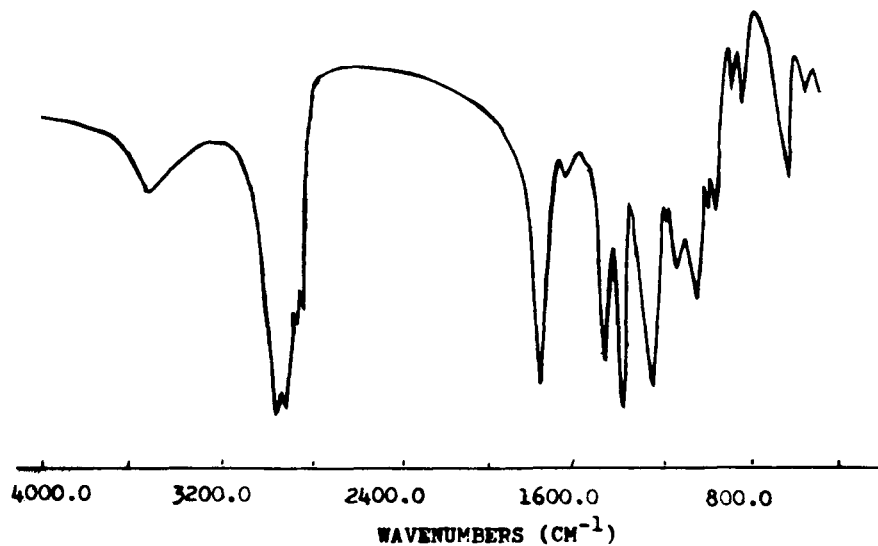


Figure 1 Infrared spectrum of PP/PVAc mixture.

Preparation of PP/PVAc Blends

The PP powder was added to the PVAc solution in CH_3OH . After thorough mixing, the mixture was dispersed into water to precipitate the PP/PVAc blend. The precipitate was then filtered, fully mixed

again, and dried in vacuum. The infrared spectrum of the PP/PVAc mixture was collected on a FI-IR spectrometer model Nicolet 5 SXC with a resolution of 2 cm^{-1} . Figure 1 represents the IR spectrum of a specimen randomly taken from the mixture. It is virtually a superimposed spectrum of IR spectra of

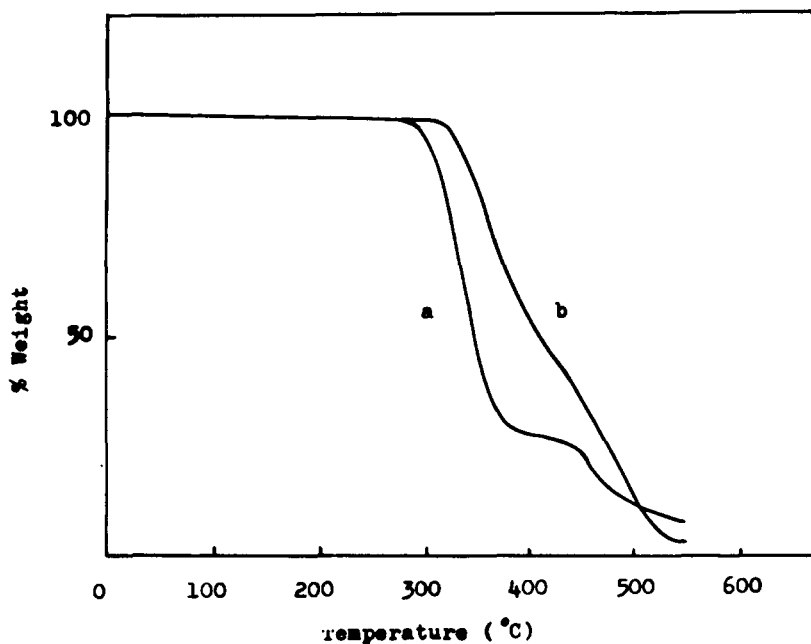


Figure 2 TGA thermograms of PVAc and PP/PVAc blend: (a) PVAc; (b) PP/PVAc (30/70).

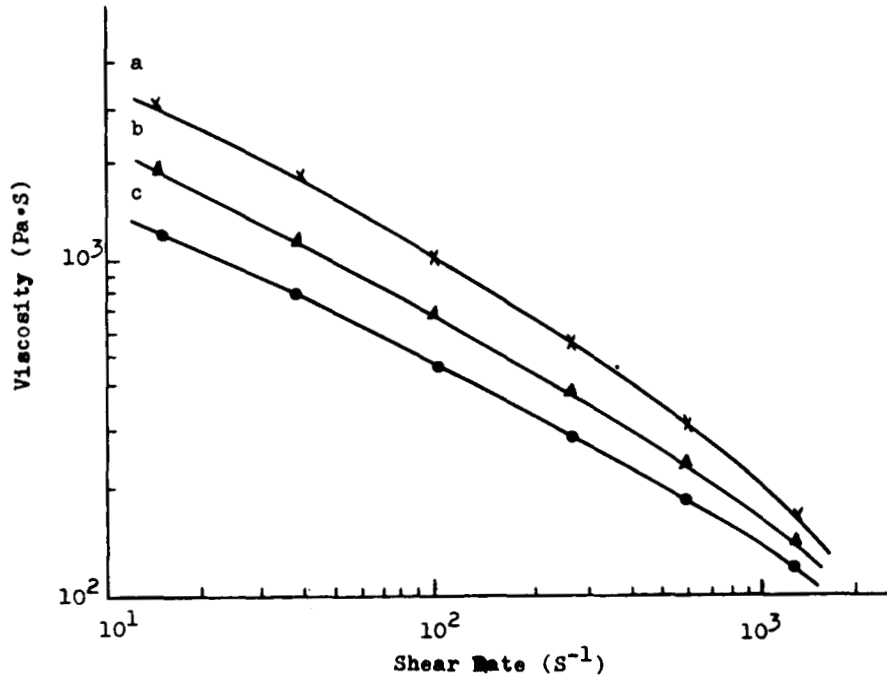


Figure 3 Viscosity vs. shear rate for (a) PP, (b) PVAc, and (c) PP/PVAc (30/70) at 220°C.

the two compounds. On this spectrum, one can see the characteristic absorption peak of carbonyl ($C=O$) group of PVAc at 1740 cm^{-1} and the inherent absorption bands at 998 , 975 , and 841 cm^{-1} of isotactic PP, indicating that PP and PVAc were well mixed. Just before spinning, the molten blend was mechanically mixed. The minor component PP was dispersed in continuous PVAc phase. They are not able to mix at the molecular level because of their incompatibility.

Preparation of Fibers

The PP, PVAc, and PP/PVAc blends were spun on a melt-spinning apparatus at 220°C. The spinning capillary has a diameter of 1 mm and a L/D ratio of 10. The as-spun filaments were drawn in hot water at 50 and 90°C, respectively.

Table I Die Swelling of Extrudates

Extrudates	PVAc	PP	PP/PVAc (30/70)
Extrudate diameter d			
Capillary diameter d_0	1.43	1.64	1.72

Dyeing of Fibers

The PP/PVAc blend fibers were dyed in a 2NBL disperse dye solution in water at 80°C for 6 h. The dyed blend fibers were cut into thin sections for the observation of a seath-core morphology with an optical microscope.

Fibrillar Morphology

In order to show the PP fibrils in the blend fibers, the blend fibers were partially immersed into hot



Figure 4 Fibrils in PP/PVAc blend fiber.

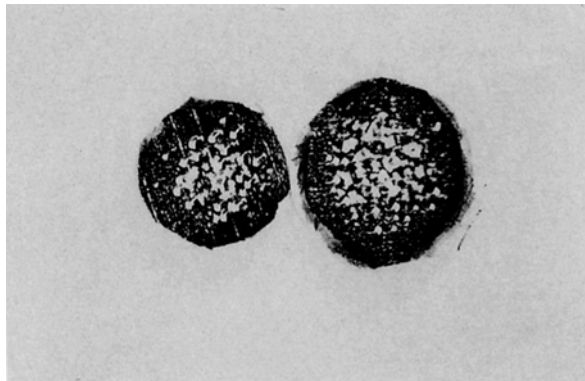


Figure 5 Cross sections of PP/PVAc blend fibers dyed with disperse dyestuff, showing a sheath-core morphology.

methanol at 60°C for some time to dissolve PVAc. The exposed PP fibrils were washed with water and dried.

Measurements

Thermal stability of polymer samples was measured on a Perkin-Elmer TG-2C instrument at a heating rate of 20°C/min in nitrogen atmosphere.

Differential scanning calorimetry (DSC) analysis for fibers was performed on a Perkin-Elmer DSC-2C thermal analyzer using 5 mg of sample at a heating rate of 20°C/min in nitrogen atmosphere. According to the measured fusion enthalpies of pure PP fiber and the PP component in the blend fiber

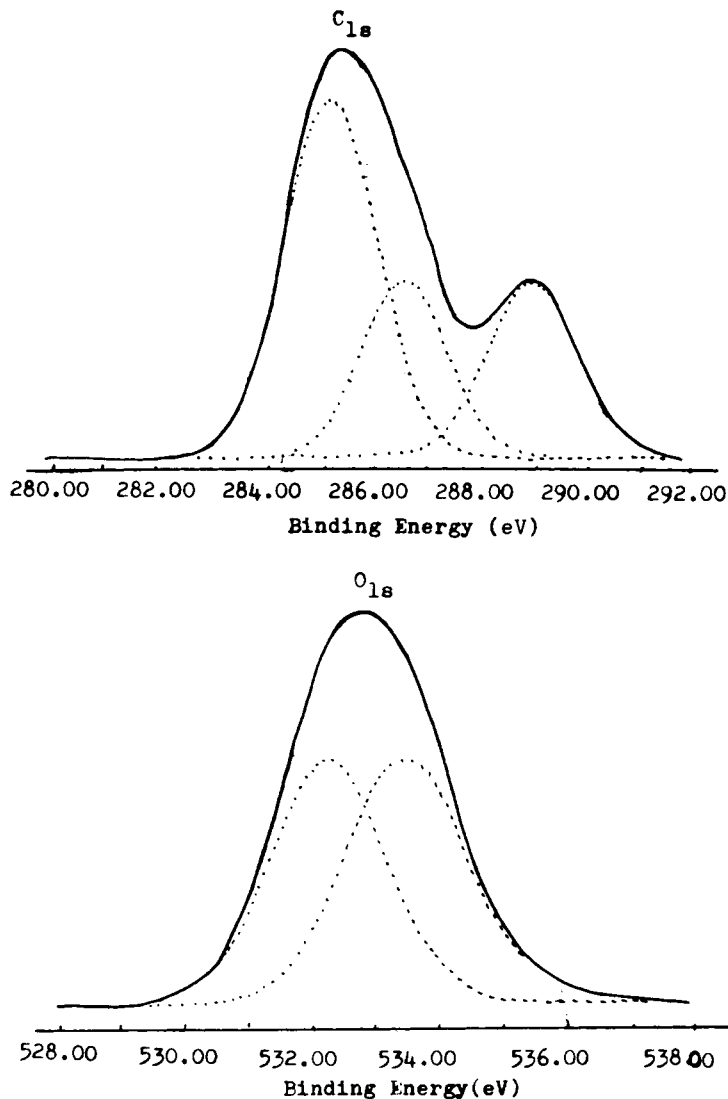


Figure 6 C_{1s} and O_{1s} XPS spectra of PVAc surface.

sample, the crystallinity of PP component of the blend fiber, relative to pure PP fiber, can be obtained.

The rheological behaviors of the melts of PP, PVAc, and of PP/PVAc blend were determined on a Instron 3211 model rheometer with a capillary L/D ratio of 40 at 220°C.

XPS spectra of the PVAc and PP/PVAc fibers were recorded with a VG MICRO MK-II spectrometer. $MgK\alpha$ exciting radiation (1254.6 eV) was employed. All binding energies quoted in this work are referenced to the C_{1s} core level at 285 eV.

A XQ-1 model electronic tensile strength tester

was employed to measure the mechanical properties for the fibers.

RESULTS AND DISCUSSION

Thermal Stability

In order to master proper melt-spinning conditions, one must understand the thermal stability of the related spinning materials. Figure 2 shows that PVAc is stable below 280°C, and the PP/PVAc (30/

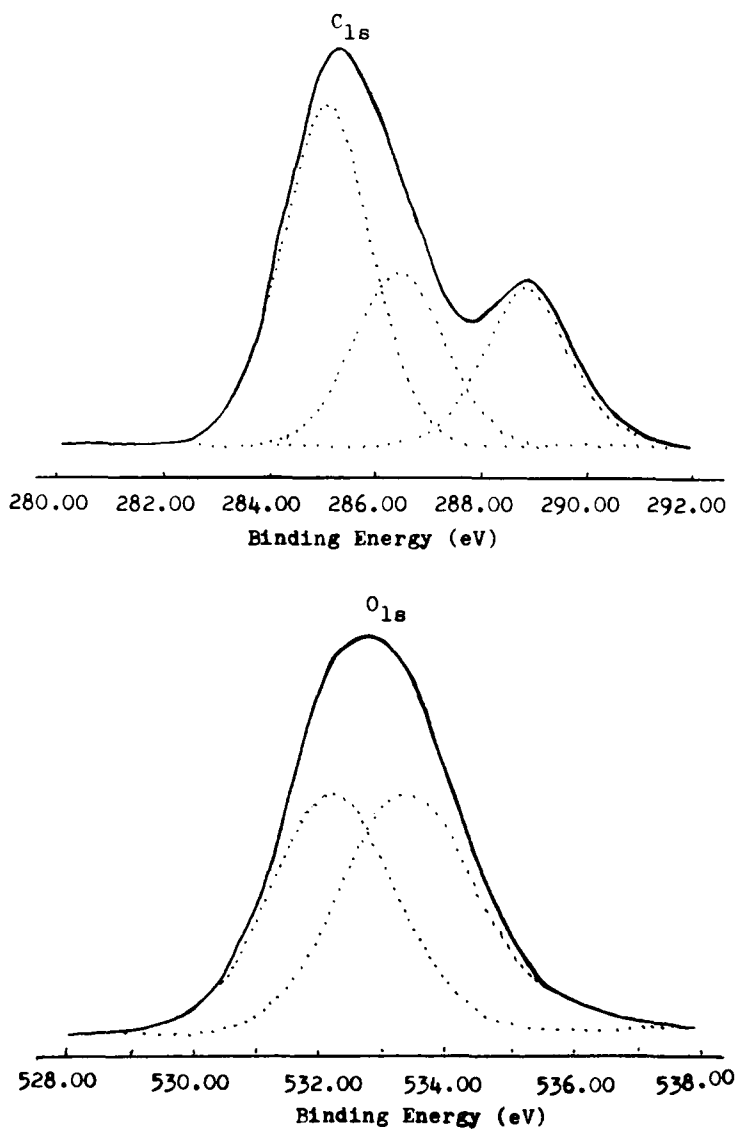


Figure 7 C_{1s} and O_{1s} XPS spectra of PP/PVAc blend fibers.

Table II Surface XPS Results of PVAc and PP/PVAc Blend Fibers

Sample	PVAc		PP/PVAc (30/70) Blend Fibers	
	Peak Position (eV)	Atom (%)	Peak Position (eV)	Atom (%)
C _{1s}	285.00	51.03	285.00	52.18
	286.45	24.53	286.50	24.56
	288.85	24.44	288.80	23.26
O _{1s}	532.25	50.07	532.20	51.36
	533.35	49.93	533.30	48.64
O/C	1/2.04		1/2.09	

70) blend exhibits higher thermal stability; it is stable below 300°C. This is favorable for melt-spinning.

Rheological Behavior

Figure 3 indicates that the melts of PP, PVAc, and PP/PVAc blend belong to shear-thinning fluid. The viscosity of the blend is lower than those of PP and PVAc because PVAc and PP are incompatible; there exist less entanglements between their molecular chains; and hence they are apt to be oriented when shear rate is increased, as a result, the apparent viscosity of the blend melt is decreased.

In contrast, as shown in Table I, the elasticity of the blend melt characterized by the die swelling is higher than that of PP and PVAc melts. According to Han,³ it could be considered that the dispersed PP droplets in the blend would dissipate less energy while flowing through the capillary than the continuous PVAc phase. Hence the dispersed PP phase would store more recoverable elastic energy than the continuous PVAc phase, and the total recoverable elastic energy at the die exit would be greater than those of single PP phase and single PVAc phase.

Fiber Structure

When an incompatible system consisting of components with different viscosities flows through a tube, the lower-viscosity component will tend to shift toward the wall and the higher-viscosity component toward the axis in terms of the energy dissipation minimum principle. It is reasonable to predict that the PP/PVAc blend fibers studied in this work will form a sheath-core morphology.

Cox⁴ investigated the deformability and hydrodynamic stability of dispersed Newtonian droplets under the action of shear stress. The deformability and stability of dispersed droplet suspensions are dependent on parameters λ and k :

$$\lambda = \eta_D / \eta_C \quad (1)$$

$$k = \gamma / (\eta_C G a) \quad (2)$$

where η_D is the viscosity of dispersed phase droplets, η_C viscosity of continuous phase, γ the interfacial tension between two liquid phases that is dependent on the compatibility of the two phases, G local shear rate, and a the radius of dispersed droplets. The larger the λ and k values, the less deformability of the liquid droplets, and vice versa. Therefore, for a given binary polymer blend prepared under certain mixing conditions, the η_D / η_C ratio becomes a critical factor in determining the disperse phase morphology in the resulting blend fiber spun at a specific spinning speed. In this work, the η_D / η_C of the melts of PP and PVAc while flowing through the capillary at 220°C and with a shear rate of $2.3 \times 10^2 \text{ s}^{-1}$ is ~ 1.4 . The formed PP fibrils in the blend fiber is shown in Figure 4. Figure 5 clearly exhibits the sheath-core morphology of the blend fibers. The PVAc matrix was deeply dyed by the disperse dye-stuff. The nonpolar PP component located in the middle of the fibers could not absorb the dye molecules and remains white.

Figures 6 and 7 show that the XPS spectra of neat PVAc and of PP/PVAc blend fibers are basically identical in shape. Table II indicates that their surface composition data are quite close to each other, implying that the surface layer of the blend fibers is mainly composed of PVAc. This result is consistent with the fiber morphology observation described above (Figs. 4 and 5). This morphology is essential for a heat-bonding fiber used in non-woven fabrics.

Table III DSC Analysis of Fibers^a

Fibers	PP	PP/PVAc (30/70)
T_m (°C)	163	158
ΔH_m (J/g)	67.9	19.4
Relative crystallinity (%)	100	95.2

^a Spun at 220°C and drawn 3 times at 50°C.

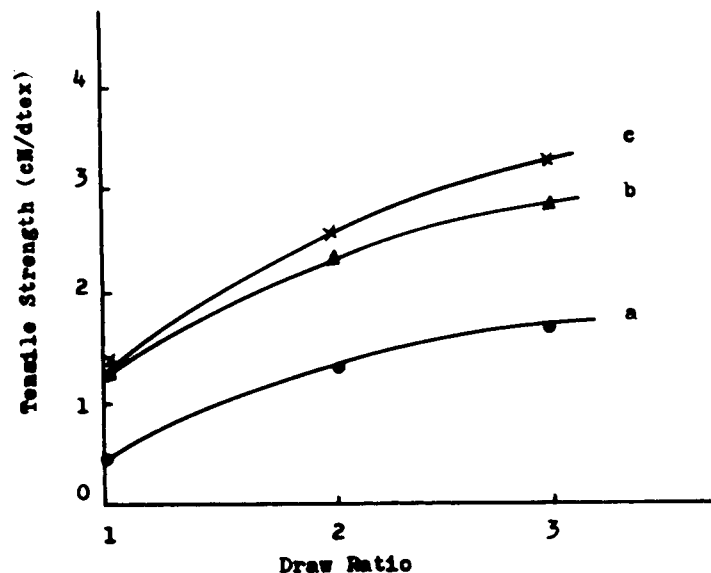


Figure 8 Tensile strength vs. draw ratio for fibers drawn at different temperatures: (a) PVAc fiber (50°C), (b) PP/PVAc blend fiber (90°C), and (c) PP/PVAc blend fiber (50°C).

Crystallinity of PP fibrils is important for the PP/PVAc blend fiber to preserve its fibrous shape in nonwoven fabrics. DSC analysis demonstrates that the crystallinity of the PP component was slightly decreased (Table III).

Mechanical Properties

Figures 8 and 9 exhibit that tensile strength and modulus of the PP/PVAc blend fibers are higher than those of PVAc fiber. It is attributable to the

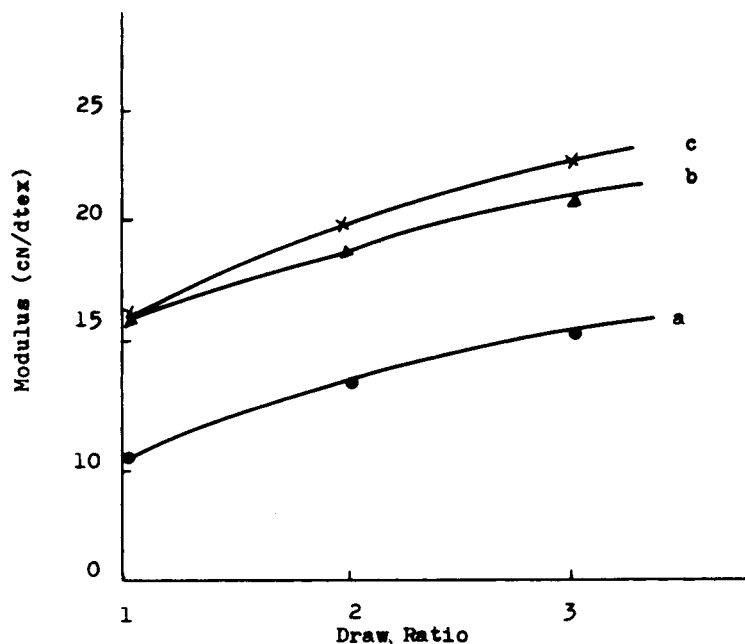


Figure 9 Modulus vs. draw ratio for fibers drawn at different temperatures: (a) PVAc fiber (50°C), (b) PP/PVAc blend fiber (90°C), and (c) PP/PVAc blend fiber (50°C).

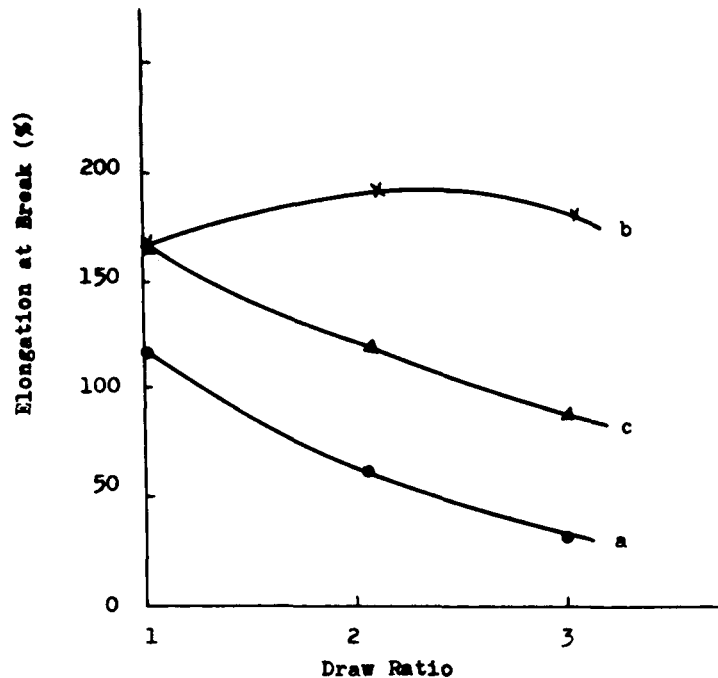


Figure 10 Elongation at break vs. draw ratio for fibers drawn at different temperatures: (a) PVAc (50°C), (b) PP/PVAc blend fiber (90°C), and (c) PP/PVAc blend fiber (50°C).

reinforcement of PP fibrils in the blend fibers. The tensile strength and modulus of the blend fibers drawn at 90°C are lower than those of blend fibers drawn at 50°C. However, the elongation at break of the blend fiber drawn at 90°C is higher than that of the blend fiber drawn at 50°C (Fig. 10). These phenomena could be explained in terms of the effect of mechanical stress and thermal energy on the molecular motion and rearrangement. The glass transition temperature, T_g , of amorphous PVAc is 28°C. At 90°C, the thermal motion of PVAc molecular chains in the blend fiber becomes so intense that the PVAc molecular segments disentangle from the network of PVAc with PP chains and offset the stress-induced orientation, leading to lower molecular orientation and hence larger elongation. While drawing at 50°C, the stress-induced orientation exceeds the disorientation caused by the thermal mo-

tion. As a result, the blend fibers drawn at 50°C possess higher orientation, strength, modulus and lower elongation, compared with those drawn at 90°C.

REFERENCES

1. Weiwei Xiao, *Modifications of Synthetic Fibers—Principles and Methods*, CUST Press, China, 1992.
2. Weiwei Xiao and Xiaoyan Zeng, *Synthetic Fiber in China*, No. 3, 17 (1993).
3. C. D. Han, *Rheology in Polymer Processing*, Academic Press, New York, 1976, p. 181.
4. R. G. Cox, *J. Fluid Mech.*, **37**, 601 (1969).

Received July 15, 1993

Accepted November 12, 1993