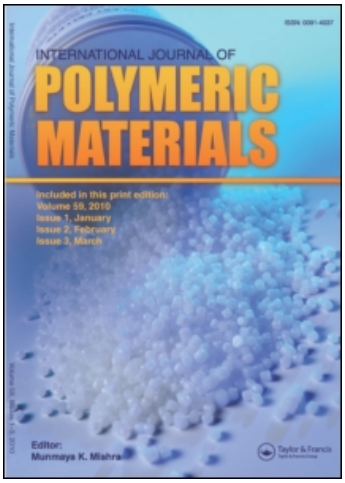

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Elastic Modulus of Fibers Spun from the Binary Polymer Blends

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Elastic Modulus of Fibers Spun from the Binary Polymer Blends

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Among mechanical properties of polypropylene fibers, spun from the blend of medium molecular weight CR-polymer with added high molecular weight polymer in the composition range of 10–50 wt%, special interest is focused on the elastic modulus in this paper. In the case of two-phase composite system, the resultant modulus is a function of the moduli of the individual pure components, the volume of the weight fraction, the geometry and packing of the disperse phase and the Poisson ratio of the matrix. In present paper only several representative equations for the calculation of elastic properties of a two-phase systems are presented. This present work is concerned with applicability of those theories to the specific case, drawn polypropylene fibers spun from blend of different polymer grades. Predicted elastic modulus calculated from the Kleiner's simplex equation is compared with the elastic modulus of drawn fibers determined from the stress *vs.* strain curve.

Keywords: Polypropylene fibers; polymer blends; elastic modulus

INTRODUCTION

Mechanical blending of two or more polymers if resulting in an improved product is often more economical and easier method to produce new polymeric material for specific applications. Many polyblends contain relatively small amounts of one of the polymers to improve processing characteristics, toughness or strength, stiffness or flexibility, surface appearance, wear properties. Blends of isotactic polypropylene (iPP) and high-density polyethylene are used to improve the impact strength, to increase environmental stress-crack resistance, modulus and heat deflection temperature. A wide variety of

other iPP polyblends have been studied in recent years [1]. Among them a few reports are dealing with blends of different molecular weights of iPP. In these studies is shown that mechanical properties can be improved by blending a fiber grade polymer with a high molecular weight polymer [2].

In the present paper elastic modulus of drawn PP filaments, produced from the blend of a fiber grade polymer with a plastic grade polymer, *i.e.*, high molecular weight polymer in the composition range of 10 – 50 wt% high molecular weight PP content, is presented.

EXPERIMENTAL

Filaments were spun from a blend of two commercial Hoechst polypropylene chips, Hostalen PPU 1780F2, a fiber grade homopolymer with MFR = 18 g/10 min and Hostalen PPN 1060 F, a plastic grade homopolymer with MFR = 2 g/10 min. Hostalen PPU 1780F2 with $\overline{M}_w = 210.000$ g/mol is a narrow molecular weight distribution polymer, so-called controlled rheology or CR-polymer, with ratio of weight to number average molecular weight ($\overline{M}_w/\overline{M}_n$) of 3.3, while Hostalen PPN 1060F with $\overline{M}_w = 280.000$ g/mol is a broad molecular weight distribution polymer, with $\overline{M}_w/\overline{M}_n = 5$. Blends composed of 90/10, 80/20, 70/30, 60/40 and 50/50 fiber/plastic grade polymer by weight were mixed manually. The melt spinning and in-line drawing of PP filaments was carried out on an Extrusion Systems Ltd. laboratory spin-draw device. Continuously moderately drawn PP filaments were additionally hot drawn to the limiting draw ratio on a Zimmer laboratory draw device.

The tensile properties of highly drawn PP filaments were measured with an Instron 6022 tensile testing machine. Samples of initial gauge length of 25 cm were stretched at a crosshead speed of 1.6 mm/s. Data obtained from the stress *versus* strain curves presented in this article are the average of about 20 parallels.

RESULTS AND DISCUSSION

Beside tenacity, elastic modulus is one of the most important properties of technical fibers. It gives a measure of the force required to

produce a small extension and describes the initial resistance to extension of a textile material.

Elastic modulus or Young's modulus (E) can be determined by measuring the tension as a function of elongation. It is obtained as a ratio stress : strain, that is as a tangent of the angle between the initial part of the stress *versus* strain curve and the horizontal axes (Eq. (1)).

$$E = \tan \alpha \tag{1}$$

Many theories have been developed to predict the modulus of two-phase blends. As a first approach the simple law of mixtures for the elastic modulus of the blends was consider [3]. The equation for the upper bound of the modulus is given by

$$E_b = E_1\phi_1 + E_2\phi_2 \tag{2}$$

The corresponding equation for the lower bound is given by

$$\frac{1}{E_b} = \frac{\phi_1}{E_1} + \frac{\phi_2}{E_2} \tag{3}$$

where E_1 and E_2 are the elastic moduli of pure components, *i.e.*, the fiber grade polymer and the plastic grade polymer, ϕ_1 and ϕ_2 are corresponding volume fractions of both components.

Kleiner *et al.* [4] proposed the following empirical equation of second order

$$E_b = E_1\phi_1 + E_2\phi_2 + \beta\phi_1\phi_2 \tag{4}$$

Empirical parameter β is obtained from $\beta = 4E_{12} - 2E_1 - 2E_2$ where E_{12} represents the modulus of the 50/50 fiber/plastic grade polymer.

If we consider the blends as a matrix with inclusions and not as a continuum of two phases, then the equations by Kerner [5], Uemura and Takayanagi [6], Halpin and Kardosz [7] are relevant. In the case of particulate-filled or two-phase composite system, the resultant modulus of the composite is a function of the moduli of the individual pure components, the volume of the weight fraction, the geometry and packing of the disperse phase and the Poisson ratio of the matrix.

The Kerner equation is

$$E_b = E_1\left(\frac{\alpha\phi_2E_2 + \beta(1-\phi_2)}{\alpha\phi_2E_1 + \beta(1-\phi_2)}\right) \tag{5}$$

where $\alpha = [(7 - 5\nu)E_1 + (8 - 10\nu)E_2]^{-1}$ and $\beta = [15(1 - \nu)]^{-1}$ with ν being Poisson's ratio.

Similar equation has been obtained by Uemura and Takayanagi, while Halpin and Tsai have shown how Kerner's equation can be rewritten in the generalised form (Eq. (6)).

$$E_b = E_1\left(\frac{1 + AB\phi_2}{1 - B\phi_2}\right) \tag{6}$$

A is an empirical constant which depends on the stress distribution in the composite and takes into account the shape and the geometry of the filler phase.

Nielsen's [8] extended Halpin and Tsai equation takes into account the packing of the filler phase (Eq. (7))

$$E_b = E_1\left(\frac{1 + AB\phi_2}{1 - B\phi_2\bar{\phi}}\right) \tag{7}$$

The packing factor $\bar{\phi}$ is determined with the maximum volumetric packing fraction ϕ_{max} (Eq. (8))

$$\bar{\phi} = 1 + \frac{1 - \phi_{max}}{\phi_{max}^2}\phi_2 \tag{8}$$

Stress-strain curves of highly drawn PP filaments spun from the pure medium molecular weight CR-polymer and from blends of this polymer with added high molecular weight polymer in the composition range of 10–50 wt% are shown in Figure 1.

The experimental data obtained in the present work were fitted to the above cited equations. Figure 2 shows plots of Eqs. (2)–(7) and the experimentally determined elastic modulus from the tensile test as the function of the composition.

It is clearly seen that the best fit to the experimental data was achieved by the Kleiner's simplex equation (Eq. (4)). In this equation term β expresses the magnitude of the deviation from linearity, that is from the ideal "rule of mixtures behaviour", and may be a relative measure of blend compatibilities. A positive β represents a nonlinear synergism, *i.e.*, criterion for compatibility, while a negative β expresses a nonlinear antagonism, criterion for incompatibility. The calculated

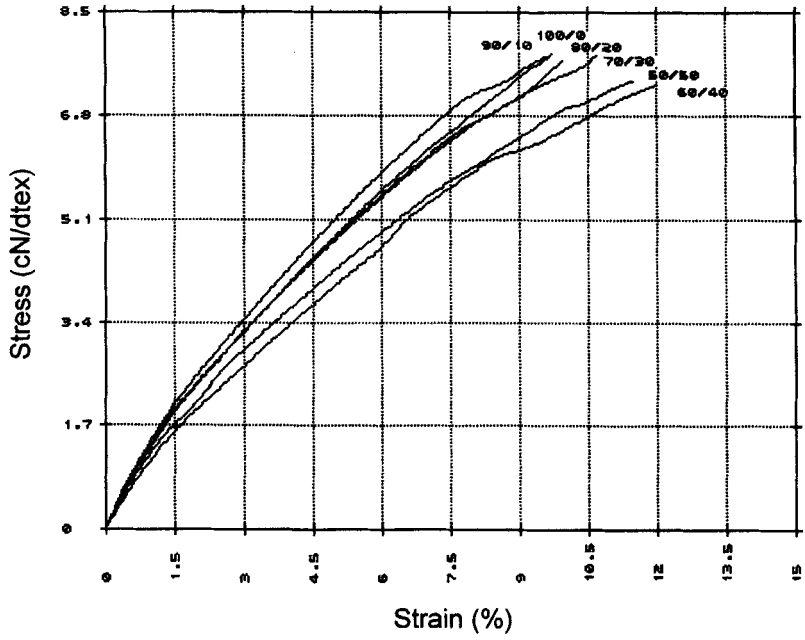

FIGURE 1 Stress *versus* strain curves of highly drawn PP filaments.

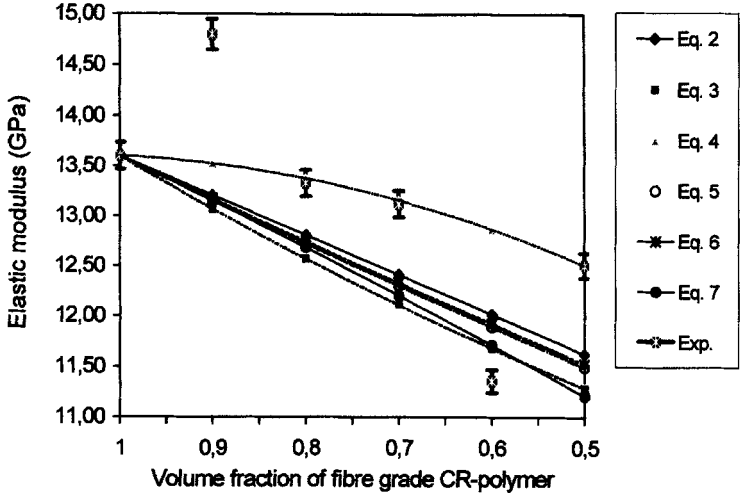

FIGURE 2 Elastic modulus as a function of the blend composition predicted by Eqs. (2)–(7) and the experimentally determined elastic modulus shown with the one percent error amount.

value of β is positive, indicating a synergistic effect of blending different polymer grades on modulus, with one exception. Addition of 40% of plastic grade polymer resulted in large negative deviation from predicted value by simplex equation.

CONCLUSION

By blending a CR-polymer of sufficiently low molecular weight with a high molecular weight polymer, maximization of elastic modulus of highly drawn PP filaments was achieved. Elastic modulus determined from the initial slope of the stress-strain curve gave the best fit to the Kleiner's simplex equation. Large positive deviation reflected by PP filaments, spun from the 90/10 fiber/plastic grade polymer, from the value predicted by the Kleiner's simplex equation, suggests good compatibility of PP polymers of different molecular weight when small percent of the plastic grade polymer is added to the fiber grade polymer.

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