Dynamic Mechanical Properties of Partially Oriented Polyester (POY) and Draw-Textured Polyester (PTY) Yarns

R. W. MILLER, *Monsanto Company, Box 12830, Pensacola, Florida 32575,* and T. MURAYAMA, *Monsanto Company, 730 Worcester Street, Springfield, Massachusetts 01151*

Synopsis

Spinning speed is one of the most important process parameters for change in properties of yarn and efficiency of polyester production. In this paper the effect of spinning speed (3000–6200 ypm) on dynamic mechanical properties is presented, and shows a good qualitative picture on the influence of structure change on the dynamic modulus and the height and position of glass transition peak on POY (partially oriented polyester) and PTY (draw-textured polyester) yarns. The dynamic moduli of POY yarns in a temperature range of 25–160°C are increased with increasing spinning speed. Large glass transition peaks (α peak) are observed for POY yarn spun at 3000 and 2800 ypm at about 98°C. This indicates that the yarns are low oriented with low crystallinity (5–6%). But the T_g of POY spun at 5600 or 6200 ypm is about 125°C and shows about 35% crystallinity with high amorphous orientation. An approximately linear relation was found between the height of the loss peak (tan δ) and the degree of amorphous orientation (f_a) by using these analyses.

INTRODUCTION

The position of the glass transition temperature of a polymer relative to room temperature determines many properties, such as mechanical behavior and dyeing. The α-dispersion in the dynamic mechanical studies is thought to be connected with the glass transition (T_g) in which polymer chain segments acquire considerable mobility. Since the motion of a segment is greatly influenced by its surroundings, the α transition should be affected by changes in structure such as changes in crystallinity and orientation.

The spinning speed is one of the most important process parameters for change in properties of yarn and efficiency of polyester production.

In this paper, the effect of spinning speed on dynamic mechanical properties is presented and shows a good qualitative picture on the influence of structure changes on the dynamic modulus, and the height and position of the glass transition peak on POY and PTY yarns.

EXPERIMENTAL

The dynamic mechanical properties of partially oriented yarn (POY) and draw-textured yarn (PTY) were measured at a constant frequency of 11 Hz with a Rheovibron viscoelastometer. This instrument applies a sinusoidal tensile strain to one end of the sample and measures the stress output at the other end. The instrument uses two transducers to read directly the absolute dynamic

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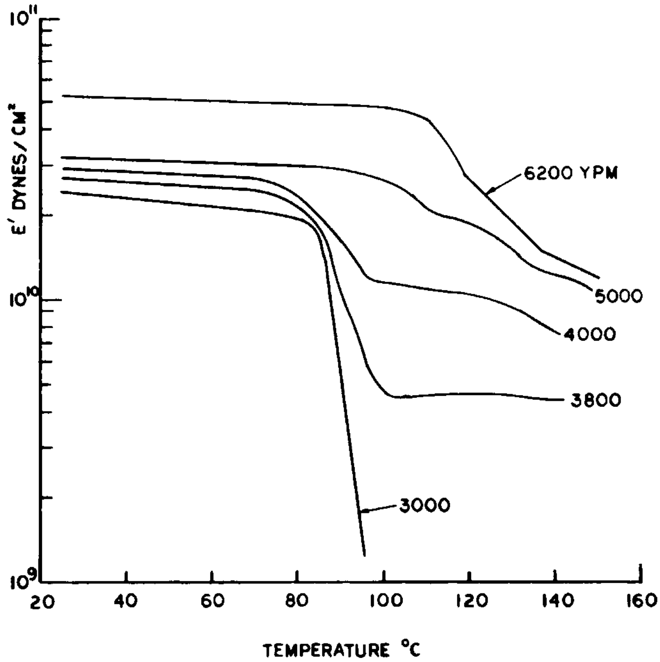

Fig. 1. Dynamic modulus (E′) of POY.

modulus E^* (the ratio of maximum stress amplitude to maximum strain amplitude) and the phase angle δ between stress and strain. From these two quantities, the real part E' (dynamic modulus) and imaginary part E'' (loss modulus) can be calculated. This method has been reported in previous studies.[1,2]

Samples were heated at a rate of 1°C/min in a nitrogen atmosphere under relaxed condition. Samples are free to shrink or expand in this condition. The changes of sample length are measured, and measurement of the tensile modulus, E', and the loss factor, tan δ, were made at increments of 10°C except near the transition region, when smaller increments were used. The morphological parameter (crystallinity and amorphous orientation f_a) measurements were conducted by X-ray, density, and sonic modulus.[3]

Wide and small angle X-ray diffraction patterns were obtained using Statton flat-film cameras with an X-ray beam generated from a copper fine focus tube operated at 40 kV and 26.25 mA. Yarn holders with 0.50 mm diameter pinholes, as well as 0.50 mm platinum general collimation entrance pinholes, were used throughout the present study.

WAXS patterns, exposed for 20 min, were evaluated using a PDP 11/34 computer interfaced to a P-1000 Obtronics Automatic Microdensitometer. The sonic modulus is measured at room temperature in a temperature and humidity controlled laboratory using a pulse propagation meter, PPM-5R, at a frequency of 5 kHz. A fixed load (0.1 gpd for POY and 0.3 gpd for PTY) is applied to straighten the yarn. In order to determine 0.3 gpd for PTY, the sonic moduli of PTY yarns at tension of 0.1, 0.15, 0.2, 0.25, 0.3, 0.4, and 0.5 gpd were measured. The sonic moduli of PTY yarn at low tension (0.1–0.2 gpd) are affected by the

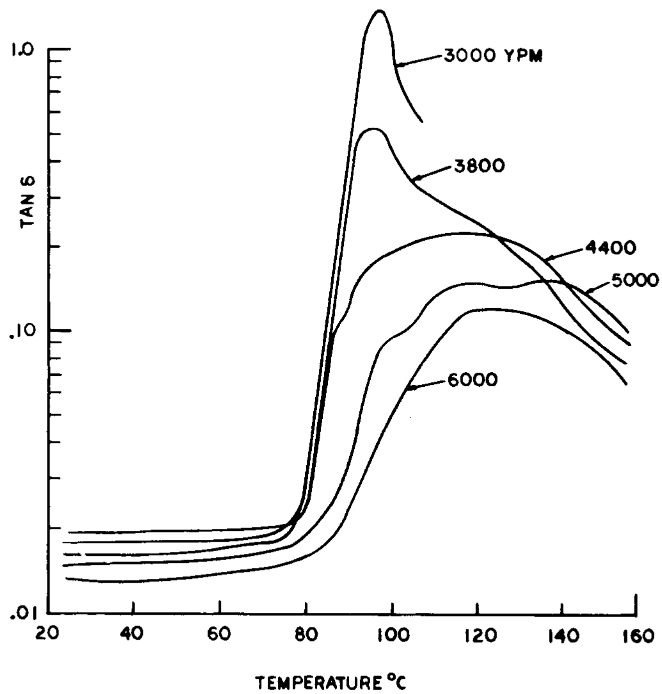

Fig. 2. Loss tangent (tan δ) of POY.

crimp structure. However, 0.25 and 0.3 gpd are enough to lose the external crimp structure completely.

Crystallinity is measured using an expanded scale TECAM density column. Samples are prewet and allowed to settle in the column for 5–6 h before reading. The sample polyester yarns were spun at 295°C and at different spinning speeds (ypm): 3000, 3800, 4400, 5000, 5600, and 6200. These POY yarns were textured under conditions of draw ratio 1.2–1.6 by the draw texturing machine.

RESULTS AND DISCUSSION

The dynamic modulus as a function of temperature of the POY yarns at different spinning speeds is shown in Figure 1. The loss tangent values for these POY yarns are shown in Figure 2. The analyses of the α dispersion (glass transition) peaks, temperature at which maximum occurs in tan δ (T_g), tan δ_{max}, and width of tan δ peak at $1/\sqrt{2}$ tan δ_{max} are summarized in Table I. The values of the degree of crystallinity and amorphous orientation obtained were shown in Table I. The dynamic moduli (E') were increased with increasing spinning speed. The temperature dependence of E' is sensitive to changes in spinning speed (3000–5000 ypm). The dynamic moduli of the POY yarn spun at spinning speed of 4400 and 5000 ypm show some modulus variation in the temperature range of 100–140°C. This is due to changes in crystallinity and orientation in the amorphous phase in the fiber structure.

TABLE I
Glass Transition Peak Parameters of POY at Different Spinning Speeds

POY spinning speed (ypm)	Temperature at which maximum occurs in tan δ (°C)	tan δ_{max}	Degree of crystallinity (%) (by density)	Width of tan δ peak at $1/\sqrt{2}$ tan δ_{max}	Amorphous orientation (f_a)
3000	96	1.35	6.3	8	0.13
3800	97	0.52	6.6	12	0.35
4400	121	0.22	10.1	42	0.50
5000	124	0.15	21.4	44	0.56
5600	125	0.13	31.9	46	0.62
6200	126	0.13	37.1	44	0.66

In the previous study on the heat crystallized PET series,[4] changes in crystallinity do not affect the room temperature value of E', but the temperature dependence E' is greatly affected by changes in crystallinity. As long as the crystalline phase is not continuous through the structure, the tensile modulus will be determined by the properties of the amorphous material. As seen in Figure 1, the dynamic tensile moduli at room temperature were increased with increasing spinning speed. At high speed the amorphous regions become oriented along with increasing crystallinity, and will greatly reduce mobility of the chains in the amorphous regions. It can be said that increase in moduli is due to the combined effect of crystallinity and amorphous orientation as increasing

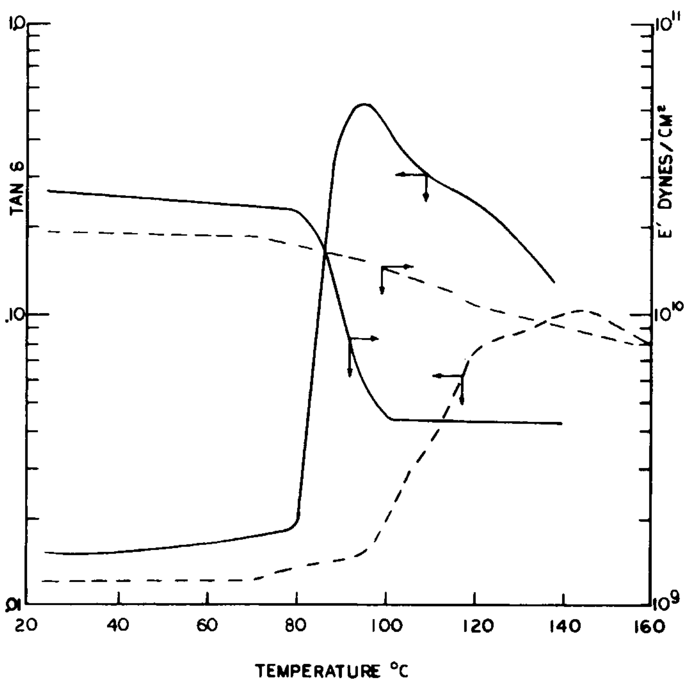

Fig. 3. Dynamic modulus and loss tangent of typical POY (—) and PTY (- - -) yarns.

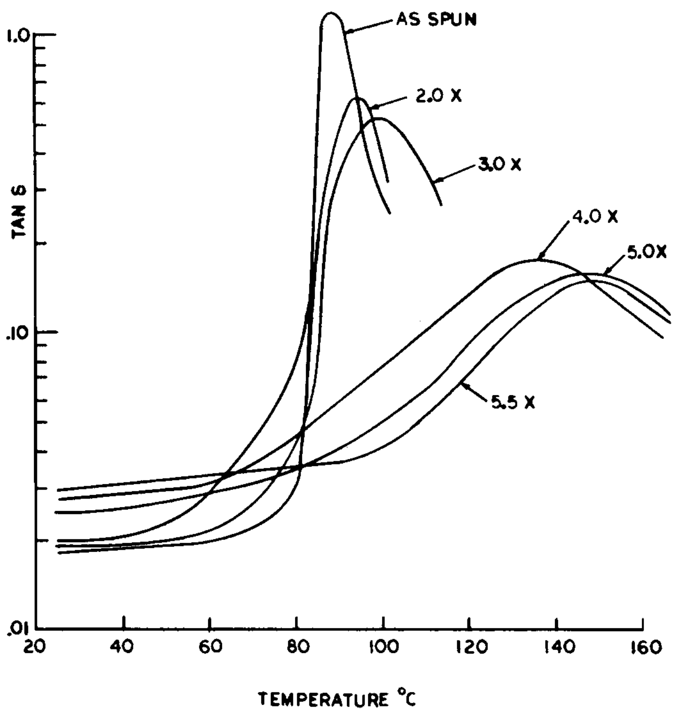

Fig. 4. Loss tangent (tan δ) of PET (flat yarn) at various draw ratios.

the structural order in POY. The values of the maximum in the loss tangent tan δ_{max} and the temperature at which the peak occurs (T_g) are given in Table I. The shift of the position of tan δ_{max} with spinning speed and crystallinity is evident, and the change in position and dispersion may be seen in Figure 2, where tan δ is plotted as a function of temperature. For example, the sample of 5000 ypm spun POY yarn has a crystallinity of 21% and T_g indicated at 124°C. However, the shift in tan δ_{max} for the drawn series (Fig. 4, flat yarn) is much greater than for the POY series.

The height of the α dispersion (glass transition peak) decreases as spinning speed increases, and it was found that there was a good relation between peak height and amorphous orientation, as seen in Figure 6. It shows that the higher

TABLE II
Glass Transition Peak Parameters of PTY

Sample no. PTY	POY spinning speed (ypm)	Temperature at which maximum occurs in tan δ (°C)	Loss tangent tan δ_{max}	Degree of crystallinity (%) (by density)	Width of tan δ peak at $1/\sqrt{2}$ tan δ_{max}	Amorphous orientation (f_a)
1	3000	135	0.088	46.1	50	0.43
2	3800	144	0.105	46.6	46	0.32
3	4400	144	0.098	44.7	44	0.34
4	5000	134	0.092	48.0	53	0.39

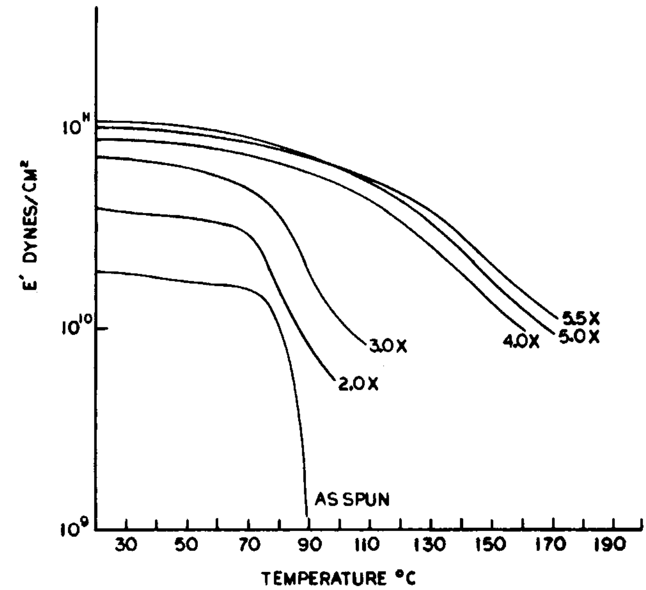

Fig. 5. Dynamic modulus (E') as a function of temperature for PET of different draw ratios.

orientation reduces internal friction of polymer chains. Our previous study,[4] Illers and Brenner,[5] and Takayanagi et al.[6] found that the height of E''_{max} changed with change in crystallinity. However, this relationship between intensity of the α peak and amorphous orientation of PET is established for the first time by using these analyses.

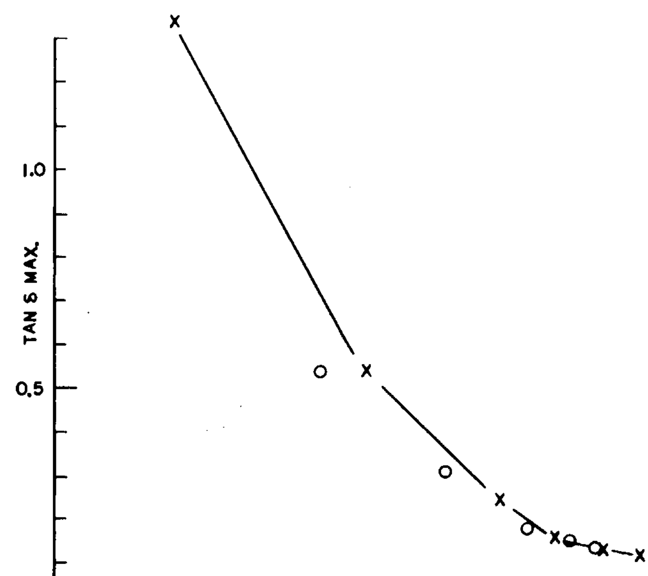

Fig. 6. Relation between tan δ_{max} and amorphous orientation (f_a).

Another feature worthy of note concerns the width of the dispersion. Since only part of the peak was measured in some cases, it was decided to define the width of the peak as the width at $1/\sqrt{2}\tan\delta_{max}$. These widths are given in Table I. As the degree of crystallinity and spinning speed increases, the peak broadens, although there is narrowing again at high spinning speed (6200 ypm).

The increase in breadth of the peak indicates that a substantial range of order exists. Table II shows the α peak parameters of the draw textured PET yarn. The POY yarns were induced by additional high heat and high stress during the texturing process. As a result, the peaks are shifted to higher temperatures. The T_g of the draw-textured PET yarn increased by 10–40°C during the texturing process. These are indications of increased crystallinity by about 20–40%. However, the amorphous orientation is decreased in the draw-textured yarn except 3000 ypm POY yarn. The typical comparison of the dynamic parameters of POY and PTY are shown in Figure 3. The dynamic moduli in the low temperature range (25–80°C) of PTY were lower than that of POY. This is due to crimp structure of the textured yarn. The dynamic moduli of PET flat yarn at different draw ratios are shown in Figure 5. There is a large modulus difference between the draw flat yarn and the textured yarn. These results reflect the characteristics of mechanical properties of PTY yarns.

CONCLUSIONS

1. The dynamic moduli of POY yarns in a temperature range of 25–160°C are increased with increasing spinning speed (3000–6200 ypm). These increases are due to a combination of increase in amorphous orientation and crystallinity in the fiber structure.

2. Large glass transition peaks (α peak) are observed for POY yarn spun at 3000 and 3800 ypm at about 98°C. This T_g and $\tan\delta_{max}$ of POY yarn indicate that the yarn are unoriented with low crystallinity (5–6%). However, the T_g of the POY spun at 5600 or 6200 ypm is about 125°C and shows about 35% crystallinity with high amorphous orientation.

3. A linear relation was found between the height of the loss peak ($\tan\delta$) and the degree of amorphous orientation (f_a).

4. The T_g of the textured PET yarn, when compared to the T_g of POY yarn, is shifted to higher temperature by about 10–40°C and maximum $\tan\delta$ values are decreased. These are indications of increased crystallinity by about 20–40%.

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