NOTES

Tensile Properties of Drawn Polyethylene Terephthalate Fibers Compared with Fibers Spun at High Windup Speeds

The variation of load during fiber extension is usually treated in the form of stress-strain curves. It has been found that the use of load-strain curves has thrown light on the mechanism of drawing of polyethylene terephthalate (PET) fibers and has enabled these drawn fibers to be compared with fibers spun at high windup speeds.

Figure 1 shows the load-strain curves of PET fibers drawn to different draw ratios, where the parent undrawn fiber was spun at 1000 mpm and had a birefringence of 0.005. Drawing was performed using a heated pin at 90°C with a feed-roll speed of 50 mpm. This series represents the properties of the initial spun yarn at increasing degrees of deformation. It is useful to consider this deformation as that of a network. Up to a DR (draw ratio) of 2.5, the initial slope of the load-strain curve and the yield load are the same. If it is assumed that a given number of emergent molecules from the network carry the load both before and after yield, then apparently up to a DR of 2.5 the number of these molecules stays constant, even though the diameter decreases. There is an analogy here to a collapsing trelliswork.

At a DR of 2.5–3.0 there is a transition. The initial modulus suddenly increases to a new constant value, while the yield load increases with DR. This implies that new load-bearing molecules have been generated in the fiber cross section, although they do not affect the initial modulus and yield in the same way.

It has been suggested that the yield plateau in a stress- or load-strain curve is due to the unfolding of folded molecules.[1] Since this plateau has almost disappeared at a DR of 2.5, the unfolding that can occur is almost complete, the most accessible folds having been removed by the drawing process. It is postulated that further drawing causes a major disruption of the molecular structure, which results in the generation of more load-bearing molecules. It would be expected that this would be accompanied by a large increase in drawing tension, and such an increase has in fact been found[2] at this draw ratio for spun fibers of the same initial birefringence of 0.005.

There is other evidence in the literature of a major structural transition at a DR of 2–3 for fibers of about the same initial undrawn properties. Globular elements of diameter 200–1000 Å in a spun fiber formed thick fibrils in this DR range.[3] The amorphous orientation determined by polarized fluorescence passes through a maximum.[4] Infrared dichroism shows that the *gauche* orientation also reaches a maximum here.[5] It is well known that crystallization commences in this DR range, but this is indicative of orientation and not necessarily symptomatic of a change in structure. However, crystal orientation measurements show[6] a very rapid increase of the orientation of the (100) plane at a DR of 2.5. DTA studies[7] show the appearance of an additional higher melting peak

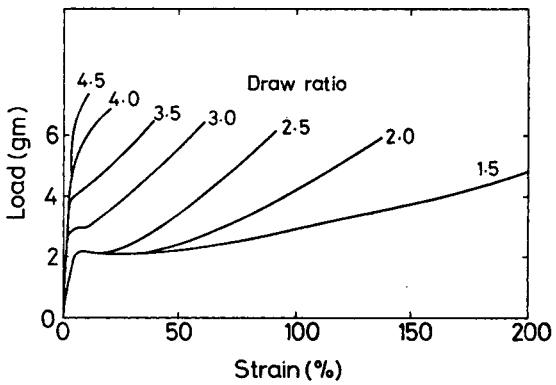

Fig. 1. Load-strain curves of drawn PET fibers.

Journal of Applied Polymer Science, Vol. 24, 301–303(1979)

0021-8995/79/0024-301$01.00

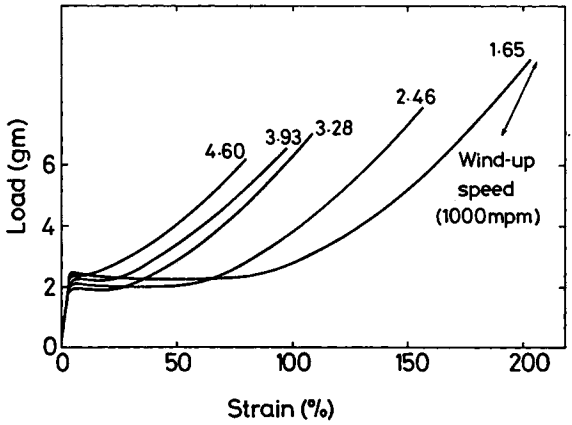

Fig. 2. Load-strain curves of spun PET fibers.

at a DR of 2.2. The amorphous orientation function of PET tapes up to a DR of 2.0 was reversible, as determined by fluorescence polarization.[8] Using the Roe and Krigbaum approach the system was calculated to correspond to a rubber with a maximum extension equivalent to a DR of 2.5.

The load-strain curves for a series of spun PET fibers at windup speeds up to 4600 mpm are shown in Figure 2. In this series the throughput of polymer per spinneret hole was kept constant. Therefore, an increase in windup speed represents increased deformation or draw-down of the fibrous extrudate immediately below the spinneret. There is a similarity of concept here to the increase in deformation in the series of drawn yarns. The fiber with a DR of 1.5 had the same extension-to-break as the fiber spun at 1650 mpm. In terms of network extensibility, these two fibers were similar and can be considered as the starting point for each series shown in Figures 1 and 2. The total deformation ratio of the drawn series was 3.0, while that of the spun series was almost the same at 2.8. In this sense the two series of fibers were therefore similar. However, Figure 2 shows that there is a major difference in the load-strain curves of the spun fibers from those of the drawn fibers. The spun fibers have not crossed any structural transition. The initial modulus and yield load are constant. There was a large difference in properties between the most deformed fibers of each series. Fibers with a DR of 4.5 had a tenacity of 52 cN/tex and an extension-to-break of 12%, whereas fibers spun at 4600 mpm had a tenacity of only 25 cN/tex and an extension-to-break of 72%.

The deformation at spinning is apparently much less efficient than that at drawing. The yield plateau has almost disappeared at the highest speed, but it is highly unlikely that the stress produced by the air drag in the spinning threadline would be sufficient to overcome the energy barrier to the structural change evident at the DR of 2.5 unless extremely high windup speeds were used.

The breaking load appears to decrease with windup speed, unlike the situation in drawing, where the breaking load increases with DR. This could be due to a progressively biased molecular orientation as the windup speed increases, leading to fewer molecules carrying the breaking load at the breaking extension. An increased fraction of more highly extended molecules (probably those at the high end of the molecular weight distribution) would be in accord with the orientation-induced crystallization of the spun PET fiber that begins at a windup speed of about 3000 mpm.

The author wishes to thank G. W. Aves for performing the experimental work and ICI Fibers for permission to publish.

References

1. M. P. W. Wilson, *Polymer*, **15**, 227 (1974).
2. R. Schroth, Faser forsch. Textiltech., **20**, 561 (1969).
3. Z. G. Vasilenko, N. V. Mikhailov, and V. A. Berestnev, *Vysokomol. Soedin, Ser. A* **12**, 1451 (1970).
4. G. E. McGraw, *J. Polym. Sci., Part A*, **8**, 1323 (1970).
5. S. A. Baranov, V. E. Geller, L. V. Papulova, and M. V. Shablygin, Khim, Volokna, No. 2, p. 17 (1970).

6. I. Kuriyama, K. Tomiita, and K. Shirakashi, *J. Text. Soc.* Jpn., **20,** 431 (1964).
7. I. Kuriyama, K. Tomiita, and K. Shirakashi, *Sen'io Gakkaishi,* **20,** 695 (1964).
8. J. H. Nobbs, D. I. Bower, and I. M. Ward, *Polymer,* **17,** 25 (1976).

H. BRODY

Imperial Chemical Industries Ltd.
Fibres Division
Harrogate, North Yorkshire
England

Received November 13, 1978