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Influence of the Gradient in Orientation on the Compressive Elastic Modulus and Yield Strength of Oriented Polypropylene

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SUMMARY

The deliberate orientation of polymers is sometimes induced by the propagation of a stable neck due to uniaxial tensile loading; this has been called cold drawing. This highly anisotropic material is often used for various types of experiments. In this paper it is shown that the necked material can be quite non-uniform over the full cross section of the neck and any assumption of uniformity, as it influences subsequent findings, can be quite erroneous.

1. INTRODUCTION

Studies of the yield behavior of oriented polymers have been reported by several investigators [1 - 6]. Hot stretching of sheets is one method that has been used to induce a deliberate orientation, or anisotropy, in an initially unoriented material. The yield behavior as a function of angular position with respect to the direction of stretching is then studied using flat strip specimens. When biaxial stress states are of concern it is most common to employ thin-walled tubes as test specimens, and it is impractical to use oriented sheet material. A satisfactory solution is to subject round tensile specimens of quite large section diameter to tensile loading until a stable neck forms and is caused to propagate to a desired length; this has been called cold drawing. Figure 1 indicates the sequence of events that lead to oriented tubular specimens; these are then subjected to various combinations of internal pressure and axial tension or compression to provide numerous yield points on an experimental yield locus.

Although extrusion or rolling might be considered as methods for inducing orienta-

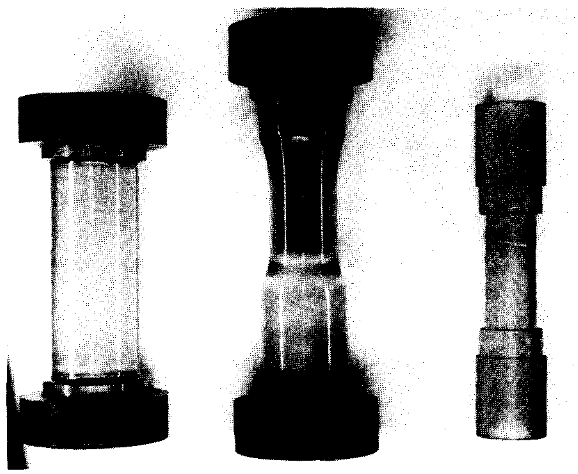

Fig. 1. The initial unoriented specimen, the specimen after orientation due to neck propagation and the tubular specimen machined from the oriented specimen.

tion, the possibility of non-uniformity across the final section thickness poses problems; redundant deformation can lead to such non-uniformities [7].

In a recent study [8] the method of inducing orientation as shown in Fig. 1 was employed using commercially obtained solid rods of polycarbonate (PC) 51 mm in diameter and of polypropylene (PP) 76 and 64 mm in diameter*. After orientation had been accomplished, numerous tests indicated that the structures of the PC bar and of the smaller bar of PP were quite uniform across the necked region so no further discussion about

*In Fig. 1, the diameter of the initial gauge section is 34 mm for PC and 51 mm for PP. The outer diameter of the machined tubes is 23 mm for PC and 17 mm for PP.

these bars is required. However, some surprising results were discovered when the larger bar of PP was used; these comprise the principal content of this communication.

2. POINT OF CONCERN

In the type of studies published earlier [5, 6] it is crucial to obtain particular measurements of the oriented material that are then used as basic values for analytical predictions. In those earlier studies, which also included high density polyethylene, it had always been observed that the highly oriented structure of the stable neck was quite uniform across the entire cross section. Thus measurements of certain macroscopic properties were obtained with little concern as to the radial location of test specimens produced from the oriented material. With the one bar of PP, however, this was not the case and it became evident that the variation in the oriented structure from the surface to the center of the necked region could introduce intolerable problems. This particular bar was not used in any further studies discussed elsewhere [8] but it was employed to provide the results presented in this paper.

3. PROCEDURE

The most extreme example of the problem is illustrated in Fig. 2; it should be understood that the large void formed as the neck propagated under tensile loading, and such a specimen finds no further use in the type of work of interest to us. The use of initial specimens from other locations of the original bar alleviated this problem but it was found that the material still displayed a variation from surface to center even though the cross section of the neck appeared sound.

Right circular cylinders 12.50 mm high and 6.35 mm in diameter were machined from the "sound" neck at the radial locations shown in Fig. 3, the height dimension being perpendicular to the axis of the stable neck. Since a proper density gradient column was not available, each specimen was carefully weighed on a chemical balance and the actual dimensions of length and diameter were measured with a vernier micrometer. This permitted the average density of each test specimen to be computed. Since the density of the six test pieces varied from 0.7143 to 0.8535 Mg m^{-3} any inaccuracies that might be questioned in regard to this method appear to be minimal. Note that the density was lowest for the specimen produced from the center of the necked region and displayed a steady increase as a function of radial position; the maximum density occurred at the outer portion of the necked section.

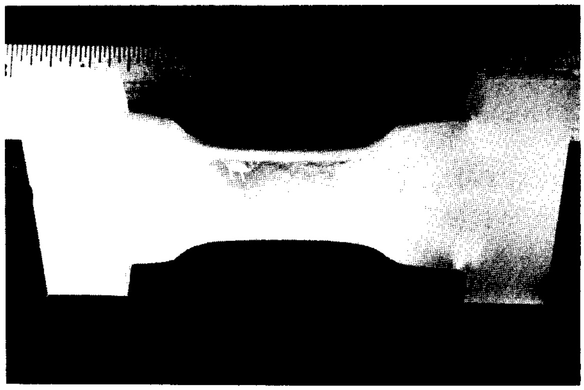

Fig. 2. An oriented specimen of PP containing a large void formed in the center of the stable neck during cold drawing.

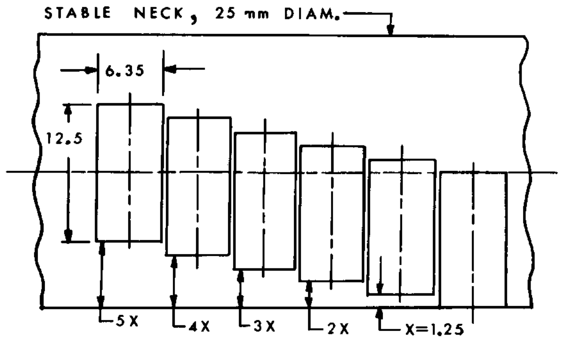

Fig. 3. The location of test specimens at various radial positions across the oriented material of the stable neck; all undesignated dimensions are in millimetres.

Standard direct compression tests were performed at room temperature on an Instron machine using a constant cross-head speed of 8.47 $\mu m\ s^{-1}$, each test being terminated when barrelling of the specimen was noted. Changes in length were detected using a method described elsewhere [8] which obviated the need to make a correction for deflection of

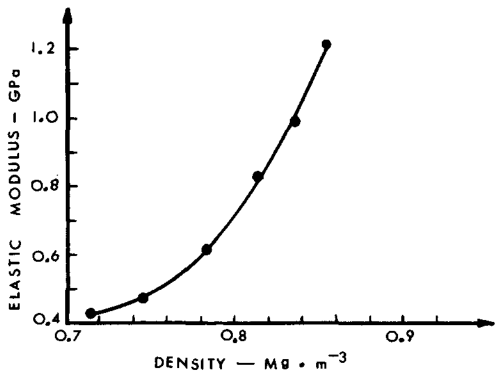

Fig. 4. The compressive elastic modulus of oriented PP as a function of density.

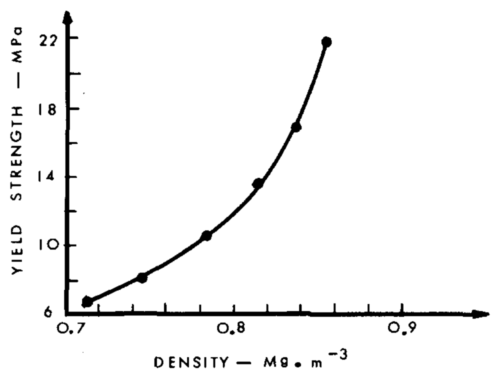

Fig. 5. The compressive yield strength of oriented PP as a function of density.

the load cell. An XY recorder was used to display the load and length changes and these data were reduced to appropriate values of stress and strain. From the plots obtained, the elastic modulus and yield strength (based on a 0.3% offset) were determined. They are shown in Figs. 4 and 5.

4. DISCUSSION

It is clear from the plots of modulus and yield strength that serious errors can be introduced in studies using oriented polymers if it is assumed *a priori* that the oriented structure resulting from stable neck propagation is uniform across the full cross section. Anyone using this method to induce orientation should be aware of these possible consequences and it is to their attention that this communication is primarily directed.

ACKNOWLEDGMENTS

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