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### *The Poisson's ratio of ultra-drawn polyethylene and polypropylene fibres using Michelson interferometry*

Recent work in this laboratory has described the preparation of ultra-oriented linear polyethylene by drawing and hydrostatic extrusion [1–3]. The products have a low strain Young's modulus comparable to glass and aluminium, and close to the theoretical value calculated for a fully extended molecule along the chain direction. In this letter we describe what we believe to be the first determination of a lateral compliance and hence a Poisson's ratio for such a high modulus oriented polymer. The results are valuable in view of the technological significance of these materials, and also because, in combination with other information they provide insight into their structure. The measurements do, however, present substantial experimental problems. For example, assuming that the Poisson's ratio is 0.5, an axial strain of 0.5% corresponds to a change in thickness of only 0.25  $\mu\text{m}$  for a typical sample of thickness 0.1 mm.

We have therefore used an optical technique for measuring the change in thickness of ultra-oriented polymer sheets under stress. The method, first reported in a recent publication [4], requires observation of the fringe shift under load when the sheet is inserted in one arm of a Michelson interferometer operating in a vertical fringe mode. Because the fringe shift arises from both a change in refractive index under stress as well as a thickness change, it is necessary to make measurements with the sample in two fluids of different refractive indices.

The polyethylene and polypropylene samples investigated here had irregular surfaces which scattered the light and masked the fringes when the samples were surrounded by air. This surface scattering was reduced to an acceptable level when the sample was immersed in a liquid of similar refractive index. We have therefore combined

measurements with the sample first surrounded by water and then silicone oil. Following the previous publication [4] we chose Cartesian axes in the sheet with the 3-axis parallel to the initial draw direction and 1 normal to the plane of sheet. The lateral compliance  $S_{23}$  measured is then given by:

$$S_{23} = \frac{\lambda(\Delta m_s^{33} - \Delta m_w^{33})}{2(n_s - n_w)t\sigma_3} = \frac{(\Delta m_s^{13} - \Delta m_w^{13})}{2(n_s - n_w)t\sigma_3}$$

In this equation  $\lambda$  is the wavelength of the monochromatic light (in this case a He–Ne laser with  $\lambda = 633 \mu\text{m}$  was used).  $n_s$  and  $n_w$  are the refractive indices of silicone oil and water,  $t$  is the thickness of the sample, which is loaded by a stress  $\sigma_3$  in the 3-direction.  $\Delta m_s^{13}$ ,  $\Delta m_w^{13}$  are the changes in fringe shift on stressing the sample in silicone oil and water respectively, for light polarized in the 1-direction.  $\Delta m_s^{33}$ ,  $\Delta m_w^{33}$  are the corresponding fringe shifts for light polarized in the 3-direction.

Measurements were undertaken on oriented tapes of linear polyethylene (LPE) and polypropylene (PP). Wide-angle X-ray diffraction data showed that the LPE tapes possessed some degree of biaxial orientation (i.e. were of orthorhombic symmetry) and the PP tapes were transversely isotropic. The tape dimensions (width approximately 15 mm, thickness  $\sim 0.1$  mm) only allowed stressing in the 3-direction, allowing two independent determinations of  $S_{23}$  from observations taken with light polarized in the 1- and 3-directions. Data showing the measured fringe shift versus the applied stress for LPE sample A are shown in Fig. 1. Each data point in this figure represents the fringe shift approximately 20 seconds after the application of the load. It can be seen that the fringe shift is linearly related to the applied stress, so that values for the lateral compliance can be obtained from the difference between the gradients of the best straight lines for the shifts observed in water and silicone oil. In a separate experiment the 20 second extensional compliance  $S_{33}$  was also deter-

TABLE I

Polymer sample	Fringe shift per unit stress ( $\times 10^6 \text{ m}^2 \text{ N}^{-1}$ )		Lateral compliance $S_{23}$ ( $\times 10^{10} \text{ m}^2 \text{ N}^{-1}$ )		Fringe shift per unit stress ( $\times 10^8 \text{ m}^2 \text{ N}^{-1}$ )		Lateral compliance $S_{23}$ ( $\times 10^{10} \text{ m}^2 \text{ N}^{-1}$ )		Mean $S_{23}$ ( $\times 10^{10} \text{ m}^2 \text{ N}^{-1}$ )		Extensional compliance $S_{23}$ ( $\times 10^{10} \text{ m}^2 \text{ N}^{-1}$ )		Poisson's ratio $\nu = S_{23}/S_{33}$		
	$\Delta m_{\text{W}}^{13}$	$\Delta m_{\text{S}}^{13}$	$\Delta m_{\text{W}}^{23}$	$\Delta m_{\text{S}}^{23}$	$\Delta m_{\text{W}}^{33}$	$\Delta m_{\text{S}}^{33}$	$\Delta m_{\text{W}}^{33}$	$\Delta m_{\text{S}}^{33}$							
Polyethylene (draw ratio 20-25)	A	0.74	0.63	-0.27 ± 0.08	0.40	0.34	-0.15 ± 0.03	0.51	-0.20	0.50	} ± 0.01	} ± 0.01	0.40 ± 0.01		
	B	0.40	0.31	-0.32 ± 0.08	0.38	0.30	-0.20 ± 0.03	0.504	± 0.05						
	C	0.40	0.29	-0.24 ± 0.08	0.37	0.29	-0.18 ± 0.03	0.49							
Polypropylene (draw ratio 10)	A	0.88	0.58	-0.41 ± 0.03	0.66	0.38	-0.38 ± 0.02	-1.04	-0.40	1.01	} ± 0.03	} ± 0.03	0.40 ± 0.03		
	B	0.79	0.50	-0.39 ± 0.03	0.64	0.33	-0.42 ± 0.02	0.97	± 0.02						

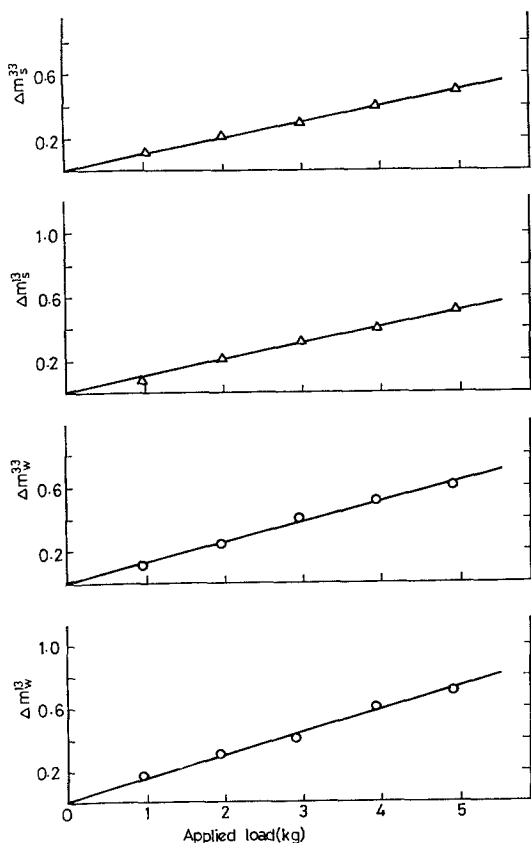


Figure 1 Fringe shift versus applied load for LPE sample A (see text).

mined as a function of applied stress, using the dead-loading creep apparatus described previously [1, 2]. These data, shown in Fig. 2, indicate that the extensional creep compliance is highly non-linear with respect to applied stress, which is well known from previous work [1, 2]. The reason that such non-linear effects are not detected in the measurement of the lateral compliance is probably as follows. The results for the two different fluid media also permit the calculation of the relevant stress-optical coefficient. This calculation shows that only a comparatively small part (between 1 and 35% depending on the difference in refractive index between liquid and sample) of the fringe shift seen in Fig. 1 is due to the thickness change, the major part arising from the dependence of sample refractive index on stress. If this latter dependence is linear, any non-linearity in the lateral compliance would be masked by experimental error.

The results for the extensional compliance  $S_{33}$  and the lateral compliance  $S_{23}$  of LPE are shown in Table I, all data corresponding to an axial strain of 0.5% and a loading time of 20 seconds. We also show similar results for tapes of oriented PP.

Although the transverse compliance measurements reported here are subject to considerable experimental error, this is not unexpected in view of the very small thickness changes involved. The experimental errors are comparable to those obtained previously in the measurements on PET film [4], and are very similar to those encountered in other techniques for measuring the lateral compliances of oriented polymer monofilaments [5, 6], which would not have sufficient sensitivity for these materials.

Although the lateral compliances  $S_{23}$  for both oriented LPE and PP are much smaller than those obtained previously for samples of lower draw ratio [5, 7], the data in Table I show that the Poisson's ratios do not change markedly with orientation. This is a further indication [8] that from a macroscopic viewpoint these ultra-oriented materials differ only in degree and not in kind from more conventional oriented polymers. The large decrease in the absolute magnitude of the extensional and lateral compliance does however arise from very considerable structural changes

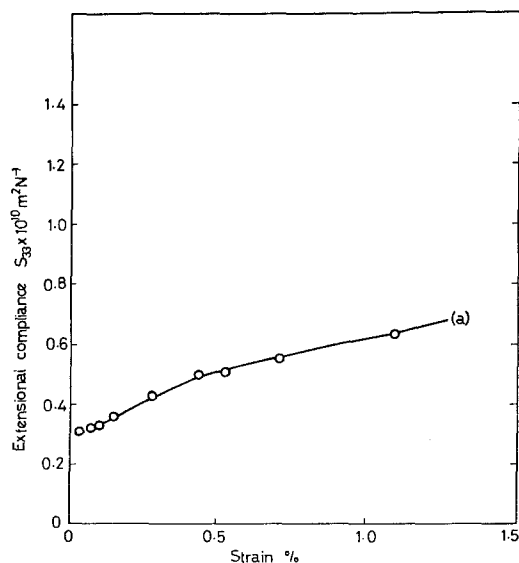


Figure 2 Extensional compliance  $S_{33}$  (20 sec) versus strain for LPE sample A.

which will be discussed elsewhere, together with their implications for the mechanical behaviour [9].

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