A technique for the measurement of the high strain rate ductility of metals

Preliminary experiments are described here in which a gas gun is used to expand thin-walled metal cylinders to failure. The expansions are recorded by high speed photography and strain rates are found to be in the range 10^4 to 5×10^4 sec^{-1}. It is considered that the method can be developed to allow rapid comparison of metal ductilities in this strain rate range.

The basic experimental system which, to date, has given the best expansion profile is shown in Fig. 1. A hollow cylinder of the metal under test, partially filled with silastomer rubber, is mounted against a rigid anvil. A gas gun [1] projects a short nylon rod into the cylinder at a velocity of ~630 m sec^{-1}. The radial momentum imparted to the material near the interface between the projectile and infill material causes the cylinder to expand.

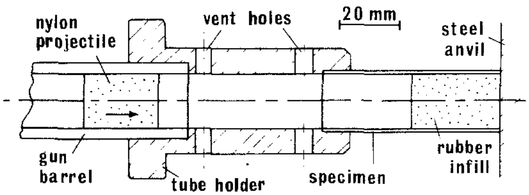

Figure 1 The experimental arrangement.

Fig. 2 shows Kerr cell photographs of the expansion of a mild steel cylinder; the time between frames was ~4 μsec. It is seen that the cylinder (of initial diameter D_0) bulges out near the impact interface; as the expansion proceeds the peak of the bulge moves slightly towards the anvil. The diameter (D) at the position indicated in Fig. 2 by a black spot, was measured at different times (t). These measurements enable calculation of the circumferential strain rate in this region, (defined here as $(\mathrm{d}D/\mathrm{d}t)/D_0$). The strain rate in the mild steel example shown is 3.0×10^4 sec^{-1}. Strain rates depend on the metal under test and on the geometry of the test cylinder. They also depend on the projectile velocity and the projectile and infill materials, by suitable choice of which a fairly wide range of strain rates can be achieved. In experiments so far values ranging from 10^4 to 5×10^4 sec^{-1} have been obtained. The longitudinal strains in different regions of the specimen can be determined from the distortion of the 3 mm grid marked on the cylinder surface. Thus it is found that the longitudinal strain rate in the vicinity of the band indicated in Fig. 2 is 0.7×10^4 sec^{-1}.

In frame 5 of Fig. 2 several longitudinal cracks have initiated around the peak of the bulge. As the deformation progresses these open up and increase in length; at a later stage rubber is forced through the cracks from inside the cylinder. The circumferential and longitudinal strains at which the cracks become visible (frame 5) are ~33% and ~11% respectively.

Examination of the fractured remains of the cylinder showed that the cracks propagated through the cylinder wall at ~45° to the surface. This suggests a shearing mechanism similar to that proposed by Hoggatt and Recht [2] to explain their observations of explosively expanded cylinders. The thickness of the fragments from most severely deformed part of the cylinder was reduced from its initial 1 mm to 0.66 mm.

Tensile tests in which linear tensile specimens are elongated at strain rates above ~10^3 sec^{-1} are difficult to interpret. This is because for specimens of reasonable length, the time for stress waves to travel the length of the test piece is significant compared with the duration of the experiment and therefore the stress and strain varies along the specimen. However, when a ring is expanded by internal loading a uniform circumferential stress is achieved and wave propagation effects are minimized [3]. Previous measurements of strain to failure at strain rates ~10^4 sec^{-1} which use this principle of radially symmetric expansion have been made by explosively expanding hollow cylinders [4, 5] or spheres [6] of the test metal. These methods have given useful results but suffer from the disadvantage that explosives handling facilities are required. The technique described in this letter has the advantages of a radial expansion system without the need for explosives. It has enabled metals to be deformed to fracture at strain rates from 10^4 to 5×10^4 sec^{-1} such that the strains and strain rates in directions perpendicular and parallel to the fracture can be determined.

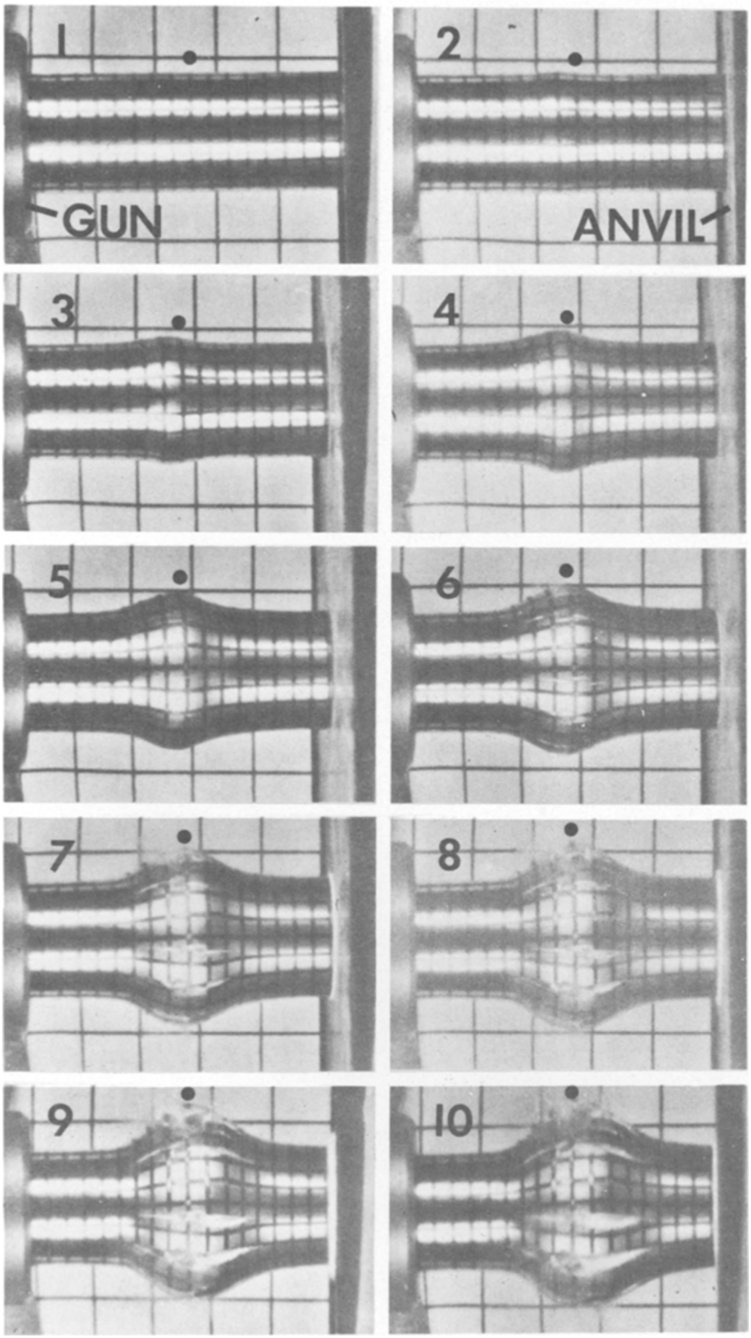

Figure 2 Kerr cell photographs, at 4 μsec between frames, showing a mild steel specimen expanded using the arrangement in Fig. 1. The projectile velocity was 632 m sec^{-1}; the background grid and the grid on the cylinder measure 10 and 3 mm respectively.

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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 μm 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 λ is the wavelength of the monochromatic light (in this case a He–Ne laser with $\lambda = 633\,\mu$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 σ_3 in the 3-direction. Δm_s^{13}, Δm_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. Δm_s^{33}, Δm_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 orthohombic symmetry) and the PP tapes were transversely isotropic. The tape dimensions (width approximately 15 mm, thickness ~ 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-