Micromorphology of ultra-high modulus polyethylene

The examination of ultra-high modulus polyethylene by scanning electron microscopy has revealed a micro-fibrilar structure. Specimens were produced by cold drawing using conditions chosen by reference to the studies described by Capaccio, Ward and co-workers [1–4]. Tensile test-pieces with gauge length approximately 20 mm, width 5 mm, were cut from a 1 mm thick sheet of high-density polyethylene prepared from granules of Rigidex 140–60, (BP Chemicals International Ltd.), by compression moulding at 160° C and rapidly quenching to room temperature. Drawing was performed at 75° C using an Instron cross-head speed of 50 mm min^{-1}. The results presented here are for drawing experiments continued to fracture, which usually occurred at a draw ratio within the range 20 to 30. Approximate values for the tensile modulus of some of the fragments were produced at room temperature using a strain rate of 3.2×10^{-4} sec^{-1}. The tangential modulus at zero strain was found to be approximately 35 GN m^{-2} for specimens with draw ratio 20 to 25, which is consistent with the results reported by Capaccio, Chapman and Ward [3].

Fragments of the drawn material approximately 10 mm long were cut, mounted on stubs, and gold-coated prior to observation in a Cambridge Instruments Stereoscan 600 electron microscope. The material sometimes showed a tendency to form axial cracks, particularly when sectioning perpendicular to the draw direction, and in some cases large pieces stripped away spontaneously and curled up, Fig. 1. A higher magnification image of

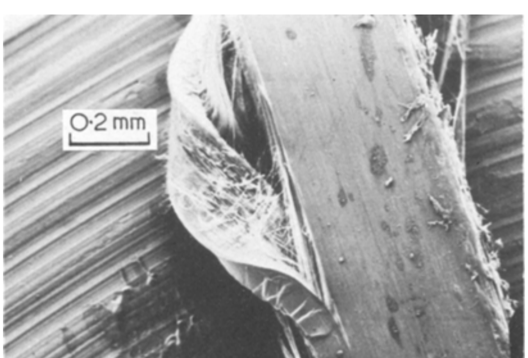

Figure 1 Ultra-high modulus polyethylene showing a fragment twisting over as it separates by means of a crack running parallel to the draw direction.

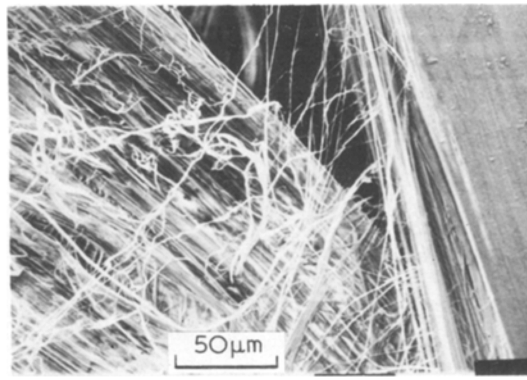

Figure 2 Part of the area shown in Fig. 1 at higher magnification. Note the low contrast striations running parallel to the draw direction on the undamaged surface.

the internal structure exposed by this fracture on a plane parallel to the draw axis is shown in Fig. 2. The fibrous morphology which has developed is clearly evident, and the surface texture of the undamaged region confirms the expectation that the alignment should be closely parallel to the draw direction. Separation of fibres appears to be easily achieved, facilitating axial fracture. Part of a developing crack is shown in Fig. 3; fibres are

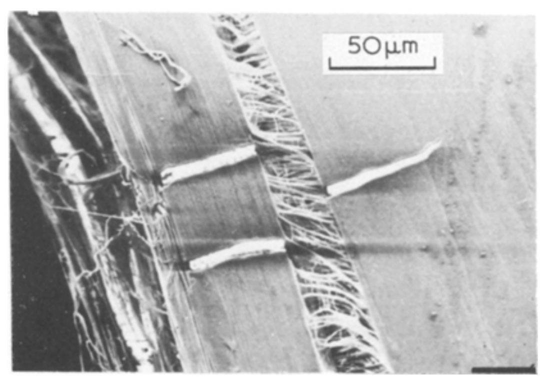

Figure 3 Part of a crack running in the draw direction. The three fissures lying perpendicular to the draw direction grew rapidly during electron microscope observation and have the bright appearance characteristic of heavily charged regions due to disruption of the conductive gold coating.

pulled across the gap between the separating surfaces, indicating that perfect alignment has not been achieved so that a path exclusively between fibres could not be found.

The fibres were found to move very readily in the electron beam and were occasionally seen to fracture. Charging was also evident, and these effects prevented recording images at high magnification. Most fibrils measured between 0.1 and 2.0

μm across, though it was impossible to set a lower limit to the size at the resolution levels achieved. The narrowest fibrils broke readily in the electron beam and defied photographic recording.

A further observation was the sudden appearance of fissure-like artefacts during electron-beam bombardment, Fig. 3. Similar features have been observed before on fracture surfaces of low density polyethylene which failed in fatigue [5]. In the previous study the fissures developed much more slowly and required much higher electron beam energy and current for production. Their source was suggested to be associated with internal stresses, which in the previous study were probably generated during the deformation cycling which was also responsible for the fatigue crack propagation. The curling of the stripped fragment shown in Fig. 1 is further evidence of high internal stresses.

The tendency to form discrete micro-fibrils is not inconsistent with the drawing mechanism proposed by Capaccio and Ward [2] involving molecular extension and alignment, including pulling out from chain-folded crystals. The ease with which a crack can be made to propagate in the draw direction may prove to be a limiting factor in the utilization of this material in load-bearing situations, though the apparent lack of cohesion between neighbouring fibrils may prove beneficial in the arrest of cracks travelling perpendicular to the draw direction.

Acknowledgement

The polyethylene used for this study was provided by BP International Ltd.

References

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Received 7 January
and accepted 18 February 1977.

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