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Crack initiation in polystyrene

B. L. EARL
Yarsley Research Laboratories Ltd, Chessington, Surrey, UK
R. J. LONERAGAN
Royal Armament Research and Development Establishment, Fort Halstead, Kent, UK
M. CROOK
Polytechnic of the South Bank, London, UK

A technique is described for demonstrating the flaws at which fracture initiates in injection-moulded polystyrene. The primary flaws are shown to be the same features as occur at the foci of secondary fractures in this polymer.

1. Introduction

Fracture of glassy plastics initiates at flaws, the nature of which has not yet been established. It has been postulated that initiation occurs at local regions of transverse orientation [1, 2], particles of dirt [3] or surface scratches [4]. Evidence has been published suggesting a random distribution of very large numbers of flaws [5] and it has frequently been reported that fracture of plastics can commence internally almost as readily as on the surface [6-10]. In the present paper it is shown that the discontinuities causing primary crack initiation in polystyrene are the same as those causing the initiation of the well-known secondary fracture features [9, 11, 12].

The principle employed in the present experiments is that if a strained test-piece is allowed to relax after the initiation of a microscopic crack within it, compressive stress is set up around the periphery of the crack. Flow occurs locally as a response to this compression. If the test-piece is subsequently fractured there will be visible markings on the fracture surface corresponding to the outline of the initiating crack present during the relaxation period. From a study of a series of such test-pieces it is possible to locate the crack-initiating features.

Injection-moulded test-pieces were employed in these tests rather than compression-moulded samples in order to eliminate the possibility of incompletely fused granule boundaries which might cause crack initiation at lower stress than the true inherent flaws. Apart from ensuring complete fusion of the polymer during test-piece preparation, the injection-moulded strips had an additional virtue in this experiment. Owing to rapid freezing in the mould, a thin layer on the surface of injection-mouldings retains much of the orientation which is present in the melt entering the mould cavity and which results from the shearing forces acting on the melt during its transference from the barrel of the moulding machine to the mould. This oriented material was aligned along the length of the test strip (which was end-gated) and therefore along the direction of the applied tensile stress. It has long been known [13, 14] that orientation present in the direction of an applied tension inhibits crazing. Consequently crazes, and subsequently cracks, formed just beneath the surface of the test-piece but tended to propagate inwards and not through the oriented layer on the surface. This resulted in considerable stabilization of the cracks which formed within the crazes and also in the generation of enhanced crack-closing forces during the resting period. (The injection-moulding process also results in a surface layer in compression which has a craze- and crack-growth inhibiting effect but which is probably insignificant compared to the effect of the orientation present.)

Flexure was chosen as the deformation method in this experiment because in practice it was found that the sequence of stressing could be carried out more conveniently and precisely in flexure than in tension with the available apparatus.

2. Experimental method

BS 903 type "E" dumb-bells were injection-moulded from Carinex GP (Shell Chemicals Ltd suspension polystyrene). These were flexed in a Type "E" Tensometer employing a span of 5.0 cm and a crosshead speed 0.25 mm sec^{-1}. This test speed was chosen because at faster speeds it was found difficult to choose the precise moment at which to stop and reverse the testing machine. Slower tests speeds seemed in practice to offer no advantage in this respect.

When the strain in the test-piece exceeded 95% of the previously-determined average deflection at fracture the machine was stopped and reversed at 2.5 mm sec^{-1}. The test-pieces were then allowed to relax at room temperature (23°C) for 30 min before being flexed to fracture by hand. The slow-crack regions on the resulting fracture surfaces were photographed in reflected white light under an optical microscope.

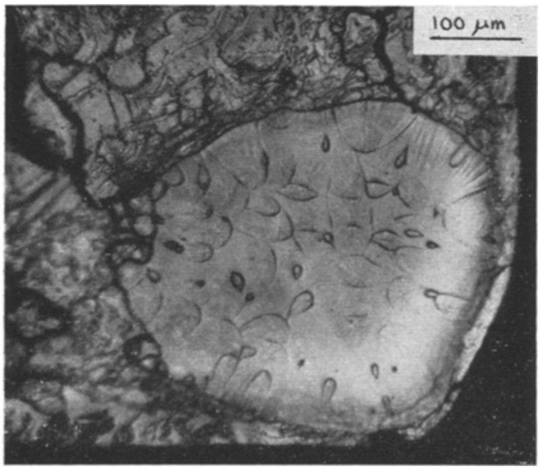

Figure 1 Injection-moulded polystyrene test-piece broken in flexure. Slow-crack region shown.

3. Results and discussion

In Fig. 1 is shown a typical slow-crack region of a fracture surface produced by flexing without any relaxation period, i.e., continuing the initial flexure to fracture. The roughly circular region covering about half of the micrograph is known to be formed by slow crack growth. On it are many secondary fractures of the type previously reported [9, 15, 16] consisting of a central point from which lines radiate and partially surrounded by a dark line of drawn polymer corresponding to the intersection of primary and secondary crack fronts. It is not apparent from this micrograph where the main crack initiated, though it is plainly within the slow-crack region. The remainder of the fracture surface was of the types known to be formed by rapid crack propagation. On this and the other three figures the longer edge of the test-piece was the surface in tension during flexure. Frequently the fracture surface contained a second slow region near to the other corner on the tension surface.

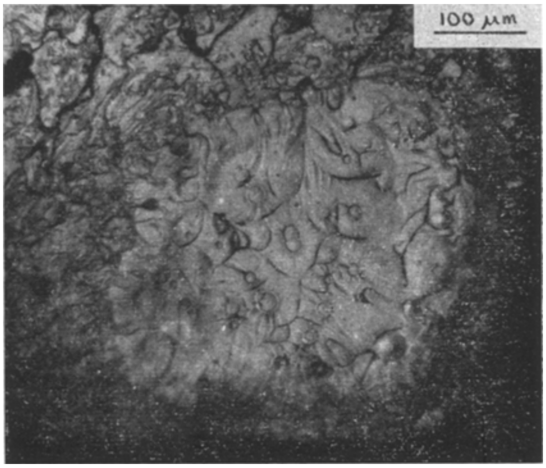

Figure 2 Injection-moulded polystyrene test-piece broken by interrupted flexure. Slow-crack region.

Fig. 2 is a typical slow region on a test-piece fractured by the interrupted flexure technique. Again the surface contains many secondary fractures but within most of these are circular markings which indicate the extent of cracks present during the relaxation period. The outline of these cracks has remained owing to deformation in this region as a result of compressive stresses exerted by the uncrazed, oriented surface layer of the test-piece. These markings clearly indicate that the fracture initiated at many points independently and that the discontinuities which lead to secondary fracture initiation are identical to the flaws which result in brittle fracture.

In Fig. 3 it is seen that the cracks have achieved a greater size prior to the relaxation period and that they have begun to coalesce. In Fig. 4 the cracks have grown and joined to form a single large slow-fracture region prior to relaxation. This photograph differs in two respects from that shown in Fig. 1. In Fig. 4 the slow-crack region is larger than in Fig. 1, which is believed to be due to continued slow-crack

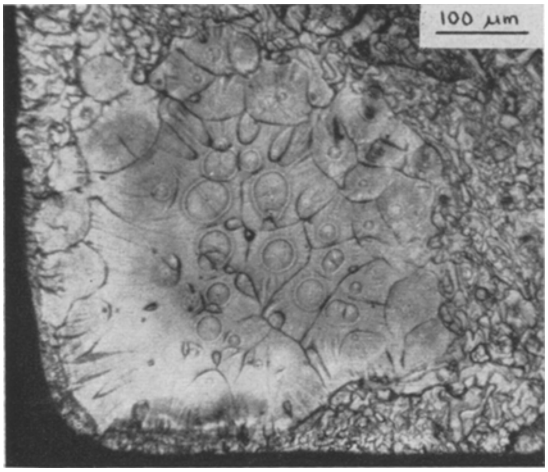

Figure 3 Injection-moulded polystyrene test-piece broken by interrupted flexure. Slow-crack region.

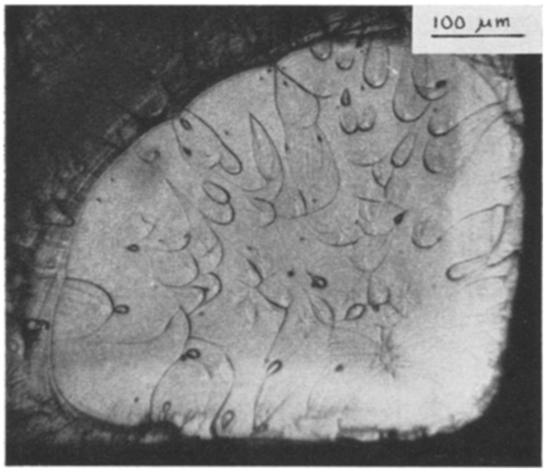

Figure 4 Injection-moulded polystyrene test-piece broken by interrupted flexure. Slow-crack region.

growth during the period of load reduction after test machine reversal. In addition, the slow-crack region is bounded by a double line of the sort formed at the periphery of cracks present during the relaxation period.

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