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Fracture Toughness Tests

The Influence of Pre-Compression on the Measured Fracture Toughness of Polymethylmethacrylate

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Summary

Compact tension specimens are subjected to applied compression prior to fracture toughness testing. The measured fracture toughness, K_Q, is approximately constant at low pre-strains but it decreases with further increase in strain due to the presence of residual tensile stresses at the notch tip. K_Q is found to be time-dependent due to relaxation of notch-tip residual stresses.

Introduction

Previous work (BEVAN 1978, NUGENT and BEVAN 1979, BEVAN and NUGENT 1983) has shown that when samples of poly(methyl-methacrylate) (PMMA) with a stress-raising circular hole are subjected to applied compression, shear bands form and crazing occurs both on loading and unloading. Shear banding in polystyrene has been studied using both specimens of similar geometry (WU and LI 1976) and notched samples (ARGON et al 1968, KRAMER 1974). In this investigation, compact tension specimens are compressed before subjecting them to fracture toughness tests.

Experimental

The compact tension specimens, of thickness 6 mm, were of nominal dimensions 15 mm by 15 mm. The length of the sharp machined notch was one-half of the effective sample width, this length/width ratio being within the range for fracture toughness tests. Fatigue notching was not used because of the tendency for shear band formation, following compressive deformation, to occur at the tip of the starter notch rather than at the fatigue crack tip.

Experiments were conducted in the sequence shown in Fig.1. Samples were first subjected to axial compression. The deformation rate (5 mm/min) and the applied strain were restricted in order to minimise the possibility of craze formation. The specimens were then allowed to recover for a pre-determined time before fracture toughness testing.

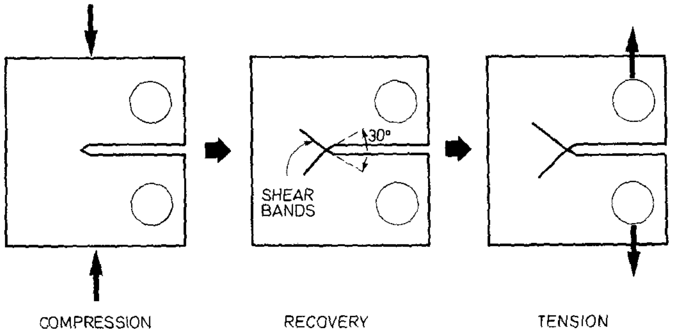

Figure 1

Test sequence

Results and Discussion

Initially, fracture toughness tests were carried out on uncompressed specimens in order to determine whether or not the machined notch was sufficiently sharp for valid measurement of the plane strain fracture toughness, K_{Ic}. The experimental value of K_{Ic} was 1.35 $MNm^{-3/2}$ which is at the upper end of the accepted range. (ASHBY and JONES 1980) for PMMA.

In the main series of experiments, samples are subjected to various pre-strains and are then allowed to recover for three minutes before fracture toughness testing. The tensile load-displacement graphs exhibit little plasticity although there is significant localised viscoplastic deformation at the notch tip following the application of high compressive strains.

The variation of the measured fracture toughness, K_Q, with applied compressive pre-strain is shown in Figure 2. Elastic applied strains do not influence the fracture toughness but the latter is affected by two competing mechanisms which operate at higher strains. Crack-tip blunting increases K_Q whereas the tensile residual stresses, produced in the crack tip region, reduce the fracture toughness. Blunting produces an increase in K_Q at 3% applied strain, which is just below the required strain for shear band formation, but in general the residual stress mechanism predominates.

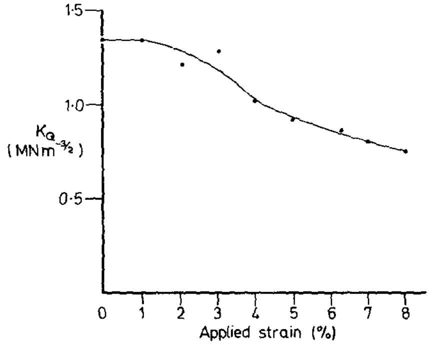

Figure 2

The effect of applied compression on the measured fracture toughness

In some cases vertical crazes form at the notch tip during compression (the local stress is tensile) at strains above 6% but there is no significant effect on K_Q. The maximum applied strain is 8% as the residual stresses produced at higher strains cause craze formation at the notch tip. Residual stress crazes are unstable and they rapidly breakdown to form cracks. These events clearly effect K_Q since the residual stresses in the tip region relax, thereby reducing the fracture toughness. Fracture toughness tests on specimens with pre-strains of above 8% are not strictly comparable with those on specimens with lower pre-strains and thus the upper limit of the pre-strains is effectively determined.

The viscoplastic nature of the deformation is such that the high strain results exhibit time-dependence. The time-dependence is measured by conducting further tests in which specimens are fracture toughness tested at various times after applying a strain of 5%. This strain is above the minimum for shear band formation but below the threshold, at the applied strain rate, for the initiation of vertical crazes. Figure 3 shows the time-dependence of the fracture toughness. The latter increases with time due to relaxation of crack-tip residual stresses. The major portion of the increase occurs within the first ten minutes when bulk recovery and shear band relaxation take place. Relaxation of the shear bands is not complete in this period and K_Q increases slightly with time while the shear bands undergo further relaxation.

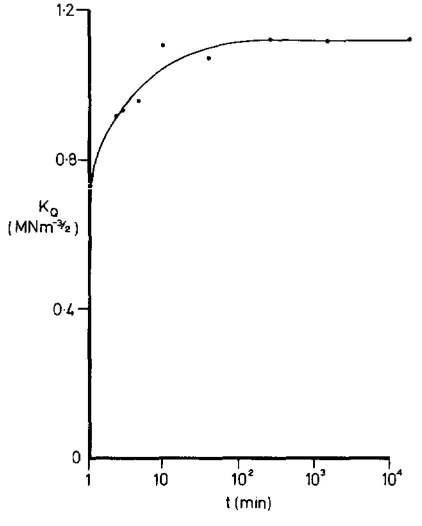

Figure 3

Time-dependence of fracture toughness

The tests described are in effect part of a cycle of an interrupted fatigue test. They therefore give an indication of the complex variation in fracture toughness in high strain fatigue loading cycles.

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