IMPACT FRACTURE TESTING OF POLY(OXY METHYLENE)

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To characterize the dynamic fracture behaviour of poly(oxy methylene), instrumented impact tests were performed with a servohydraulic test system using single edge notched bending (SENB) specimens. The primary objective of this study was to develop and implement a test methodology and a data recording and reduction scheme for various impact rates (0.01 to 7.9 m/s). As far as the instrumentation is concerned, load-time signals were measured and recorded using an instrumented tup equipped with a piezo load cell and strain gages, respectively. Furthermore, the time-to-fracture was detected with different strain gage types applied to the specimen side surfaces in the immediate vicinity of the crack tip. The data reduction to determine dynamic fracture toughness values was carried out according to different procedures taking account of the specific impact rates. Due to the viscoelastic nature of plastics, the strain rate dependence of the elastic modulus required for the calculation of dynamic fracture toughness values was determined experimentally.

INTRODUCTION

For many engineering applications, impact fracture behavior is of prime practical importance. While impact properties of plastics are usually characterized in terms of notched or unnotched impact fracture energies, there has been an increasing tendency to also apply fracture mechanics techniques over the last decade (1- 4). However, due to dynamic effects several special problems are encountered in high rate fracture testing (2, 4, 5). While the control of dynamic effects at impact rates up to 1 m/s frequently makes use of mechanical damping in the load transmission by placing a soft pad between the tup and the specimen (1), for intermediate impact rates from above 1 m/s to 10 m/s, a technique referred to as "dynamic key curve" (DKC) method as recently proposed by Kalthoff und Böhme (2,6,8) may be applied. To apply the latter methodology to plastics, strain rate dependent values for Young's modulus, E, are required. The objective of this study was to develop, implement and compare different test methodologies and data recording and reduction schemes to determine dynamic fracture toughness values for poly(oxy methylene) (POM) at impact rates ranging from 0.01 to 7.9 m/s.

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EXPERIMENTAL

Materials and Specimens

The material used in this study was a commercial grade POM (Hostaform C 13021, Hoechst AG, Frankfurt/Main, D) and was supplied as extruded sheets with a nominal thickness of 9 mm. Single edge notched bending (SENB) specimens according to a configuration defined by the European Structural Integrity Society (ESIS) (5) and Charpy-type specimens (8) were machined from the sheets and subsequently notched and razor blade precracked parallel to the extrusion direction. For impact rates up to 1 m/s ESIS specimens with a geometry of 9x18x90 mm and Charpy specimens with dimensions of 9x10x55 mm were used. The normalized crack length, a/W (a being the crack length and W the specimen width), ranged from 0.1 to 0.7 in the first case and 0.3 to 0.5 in the second case. In the tests above 1 m/s, Charpy specimens with a normalized crack length of $a/W \cong 0.3$ were applied. In addition, conventional tensile and bending specimens, and impact tensile specimens were used to determine strain rate dependent modulus values.

Testing and Data Acquisition

A fully digitalized servohydraulic test machine (MTS 831.59 Polymer Test System, MTS Corp., Minneapolis) was used to perform all of the tests. For the two fracture specimen types tested, appropriate specimen support fixtures (ESIS (1) and Charpy (8)) were selected. As to the striker, three different tups were applied. A Ti alloy tup equipped with a piezo load cell (Kistler 9041A) was used for impact rates up to 1 m/s. In these tests the load-point displacement associated with the striker movement was determined from an LVDT signal of the piston.

For impact rates above 1 m/s, Ti alloy tups instrumented with two types of strain gages - WK-05-125AD-350 and ED-DY-125AD-350 (Measurements Group Inc., Raleigh) - were used to record an uncalibrated signal. Moreover, in this test speed range some specimens were also instrumented with strain gages near the crack tip (strain gage type for ESIS specimens: CEA-06-062UW-350; strain gage type for Charpy specimens: CEA-06-032UW-120).

Data Reduction

Typical examples of force/load-point displacement curves for impact rates of 1 m/s are shown in Figure 1. While the recorded damped signal is of sufficient quality to directly determine the fracture force, F_Q, and the fracture energy, U_Q, significant force oscillations are visible in the non-damped tup signals. While in these latter instances values for U_Q were also obtained by direct integration of the force/load-point displacement curve, values for F_Q were determined by calculating an average straight line through the recorded signal which was then intersected with the force drop signal at fracture. Hence, for impact rates up to 1 m/s, values for the fracture toughness, K_{Ic}, and the critical strain energy release rate, G_{Ic}, could be obtained directly from experimental F_Q and U_Q values, respectively, based on well known relationships described elsewhere (1).

Uncalibrated traces of tup and specimen signals for POM impacted at 3 and 7.9 m/s, respectively, are shown in Figure 2 also indicating the time-to-fracture, t_f. For both impact rates t_f was found to be longer for the tup signal. This is probably caused by inertia effects associated with the striker movement and possibly also by the load-point/strain gage distance at the tup. As these effects are not present with instrumented specimens, the latter technique appears to be superior.

To deduce dynamic fracture toughness values from instrumented specimen signals, both the DKC method (2, 8) mentioned above and a strain gage calibration (SGC) method (2) were used. According to the DKC method K_{Ic} can be determined from the predicted impact response curve, $k_I^{dyn}(t)$, by using $t=t_f$ for the time, t, as follows:

$$K_{Id} = \frac{EY(a/W)}{\sqrt{W}C_s^{*}\left(1+{}^{C_m}\!/\!{}_{C_s}\right)} v_0 t_f k^{dyn}(t=t_f) \qquad (1)$$

In agreement with experimental data shown below, the elastic modulus required for this calculation was chosen to be 3000 MPa for the POM investigated. Further details as to the instrumentation, data acquisition and data reduction procedure are discribed elsewhere (9).

RESULTS AND DISCUSSION

To obtain appropriate impact modulus values (E_{mt}, E_{mb}, E_{dmt}), experiments were performed under monotonic tension at 0.001 m/s (60 mm/min) and monotonic bending at 0.1 m/s, and under cyclic loading conditions in the frequency range from 1 to 300 Hz. In addition, impact modulus values (E_{itt}, E_{itc}, E_{ifm}) were determined from impact tensile tests, fracture tests based on the compliance method (10) and based on the well-known relationship between K_{Ic} and G_{Ic} (1). The loading rates of the various tests were transformed into corresponding strain rate values by a procedure described in (9).

The strain rate dependence of the modulus numbers obtained is depicted in Figure 3. Considering the vastly differing test methodologies and data reduction schemes, good agreement is found between the data of various test techniques, with modulus values rising from about 2800 MPa to 3500 MPa in the strain rate range of 0.01 to 50 s^{-1}.

Finally, K_{Ic}-values for POM are plotted in Figure 4 over the entire impact rate range investigated. Again, taking the complexity of the various tests and data acquisition and reduction methods into account, all data are seen to be within a rather narrow scatterband with a clear tendency for decreasing fracture toughness values with increasing impact rate.

SUMMARY AND CONCLUSIONS

To characterize the dynamic fracture behavior of POM instrumented impact tests were performed in the impact rate range from 0.1 to 7.9 m/s with a servohydraulic test system using SENB specimens of two different geometries, two different test fixtures and load transducers, and applying various data acquisition and reduction methods. While the recorded damped signal up to 1 m/s is of sufficient quality to directly determine the fracture force and the fracture energy required for K_{Ic} and G_{Ic} calculations, respectively, at impact rates above 1 m/s, specimen instrumentation is to be preferred over tup instrumentation. For these impact rates good agreement is found between the DKC and SGC data reduction method. Furthermore, K_{Ic} values were found to be independent of specimen geometry and the test fixture used.

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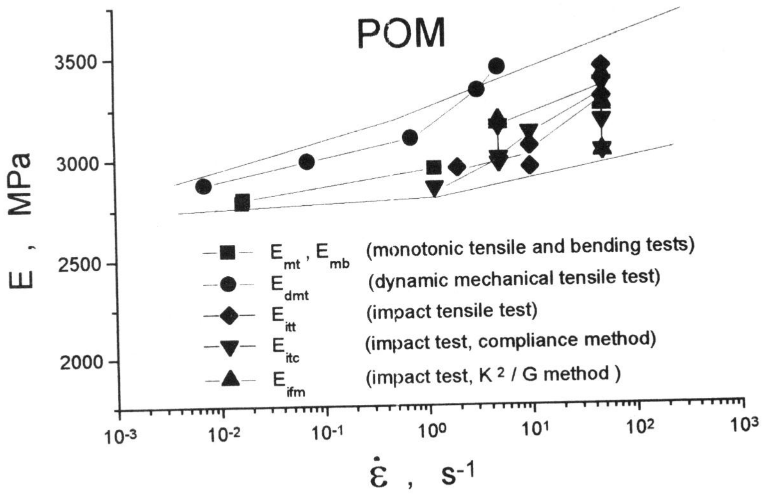

Figure 3 Strain rate dependence of modulus values for POM from various test techniques

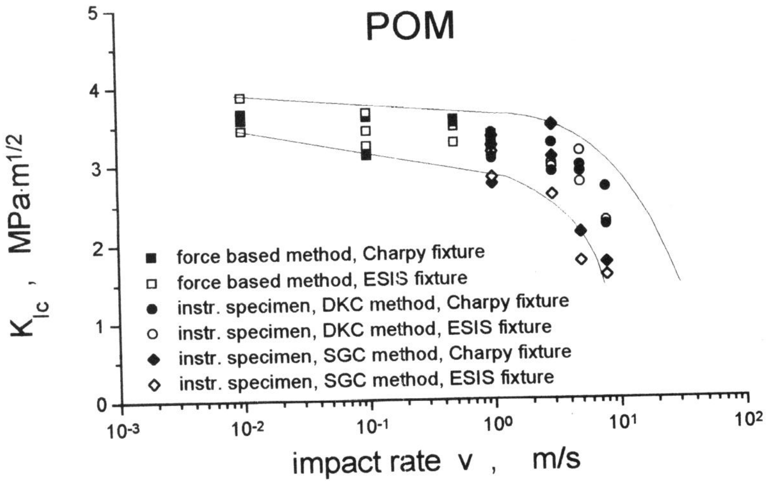

Figure 4 Impact rate dependence of fracture toughness in POM

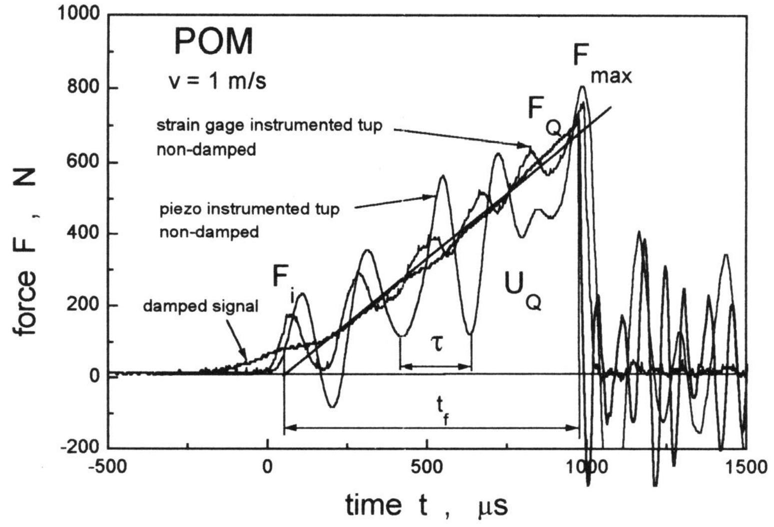

Figure 1 Force/load-point displacement records for POM at impact rates 1 m/s for various test conditicns

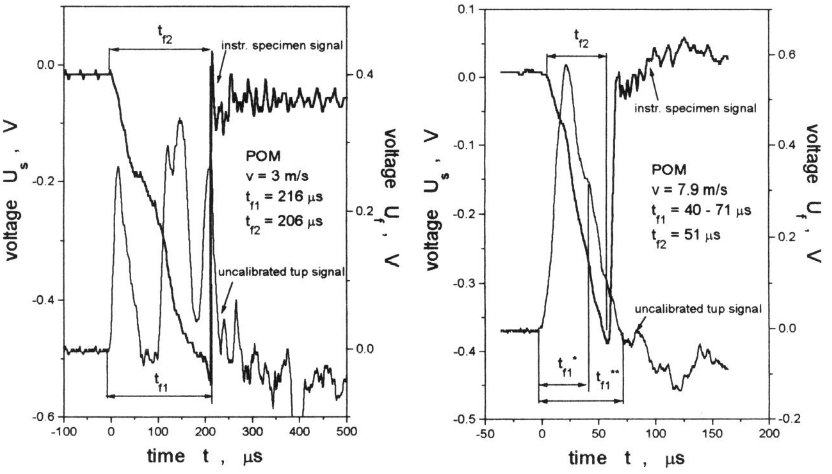

Figure 2 Uncalibrated tup and specimen signals for POM at impact rates above 1 m/s