# A COMPARISON OF TWO DYNAMIC J-R TEST METHODS FOR THE ESIS TC5 COMMITTEE FIRST ROUND-ROBIN PROGRAMME

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Impact tests were performed to determine dynamic J-R curves for a structural steel. The Chipperfield and three-point bend arrest multi-test piece techniques were compared with static results. It was found that the fracture toughness of the steel increased with loading rate and that the two methods gave similar results. Size effects were investigated by testing different thickness test pieces. The use of on-test piece straingauges for load measurement was also evaluated.

## INTRODUCTION

As the Imperial College contribution to the current exploratory round robin being conducted by ESIS TC5 Technical Sub-committee on Dynamic Testing at Intermediate Rates, a programme of impact tests was performed to measure dynamic J-R curves for BS 4360-50E normalised carbon-manganese structural steel. Two multi-test piece techniques were compared - the Chipperfield and three-point bend (3PB) arrest methods. A static test was performed to allow dynamic and static results to be compared.

## EXPERIMENTAL

All impact tests were carried out on the 3 kJ drop weight testing machine shown in fig 1(a). The test pieces had width W=40mm, span S=160mm and thickness values of B=20 or 40mm, with T-L orientation and were not sidegrooved. For the Chipperfield tests [1,2] at 5m/s, crack extension was controlled by the specimen shoulder width. For the 3PB tests at impact velocities between 3.8 and 2.3 m/s, crack extension was controlled by limiting the available striker energy, see Böhme [3].

Photocells triggered by a mirror measured the velocity of the striker just before impact, fig 1(b). The anvils used for 3PB and for Chipperfield tests are shown in fig 1(c),(d). The Chipperfield anvils were higher than the 3PB ones, to avoid the striker re-contacting the test piece as it reached the end of its travel.

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Traces from the load cell, strain gauge and instrumented anvils (3PB tests) were recorded using the equipment shown in fig 1(b). Two Gould 20MHz 4-channel digital oscilloscopes were used, triggered by one of the photocells. Experimental records were transferred to a computer for storage and manipulated using the Dadisp data package and later transfered to a Sun workstation for further evaluation.

After heat-tinting and breaking open the test pieces, the fatigue precrack and final crack length was measured using the BS 5762 three-point average technique for the 40mm thick pieces, and a five-point average for the 20mm thick pieces, which exhibited considerable side branching and an uneven crack front. One unloading compliance test was performed on a 3PB 20mm strain gauged test piece in order to obtain a static J-R curve. Compliance estimates for crack determination were based on CMOD using an ASTM E813 program developed in [4].

## ANALYSIS OF RESULTS

J was calculated from

$$J = \frac{2U}{B\,(W-a)} \qquad (1)$$

where U is the work done from the load-displacement (P-d) diagram.

For dynamic tests, where load-time (P-t) and displacement -time (d-t) traces are recorded, the area under the P-d diagram is often calculated using a constant velocity assumption. This describes the Chipperfield tests acceptably, but is inadequate for the 3PB tests, where the velocity varies from an initial value at impact down to zero. A program was developed to calculate the energy absorbed by splitting the P-t graph into segments and integrating incrementally. The first segment was calculated at the measured impact velocity. The velocity was then corrected to allow for deceleration of the striker and the new value used to evaluate the second segment, and so on. Inputs required were the P-t trace, the impact velocity, the weight of the assembly and the calibration factor for the load cell. The portion of the graph to be evaluated and a zero datum for load were also defined. The program output load, velocity, displacement and energy absorbed at time increments.

The energy calculated above is that transferred from the striker to the test piece. Not all this energy is used in plastically deforming the test piece and propagating the crack; some is dissipated in ways not relevant to the J evaluation. An attempt has been made to quantify these errors, in order to eliminate them from the net calculated energy. The two test configurations gave different sources of energy loss, but common to both

3PB and Chipperfield methods were:
(a) Indentation at the point of impact. To evaluate this, static tests were performed by loading 20mm and 40mm test pieces on a flat surface up to the maximum loads (first peak on the P-t curve) achieved during impact. The indentation energy calculated from the area under the resulting P-d record was negligible, with the test pieces exhibiting no significant permanent deformation. It is probable that the indentation visible after the tests was caused as the testpiece hinged back around the striker.
(b) Friction between the test piece and anvils. This was corrected using

$$U_f = \text{Force} \times \text{Distance} = \mu P_s \times d_{tot} \qquad (2)$$

where $P_s$ is the load at each of the supports ($P_s=P/2$), $\mu$ the friction coefficient taken as 0.15 and $d_{tot}$ is the total applicable distance measured from the friction marks for 3PB pieces and taken as twice the shoulder width for Chipperfield pieces.
(c) In Chipperfield tests only, the test piece is pushed through the anvils at the striker, gaining kinetic energy in the process. This energy was calculated from

$$U_k = (1/2)mv^2 \qquad (3)$$

where m is the mass of the test piece and v is the velocity of the striker at the end of the test, as calculated by the energy program.
(d) For 3PB tests only, the energy is calculated from the kinetic energy of the striker at impact. The striker however travels further before it arrests. The height difference between the impact and the arrest points represents potential energy transferred to the test piece, which was calculated from $U_h = m\,g\,h_c$ where m is the mass of the weight assembly, and $h_c$ is the correction height measured on each test piece after the test.

## STRAINGAUGED TEST PIECES

During an impact test the signal from the striker load cell exhibits high levels of oscillation, particularly close to the time of contact. The signal from a calibrated straingauge on the neutral axis of the test piece is smooth and easier to evaluate; also a gauge near the crack tip may be more representative of the true fracture conditions since the forces dissipated in friction, indentation and test piece kinetic energy is excluded. Twelve test pieces were straingauged, using Micro Measurements 1.5mm gauge length constantan-polyimide gauges, hot bonded with solvent-thinned epoxy adhesive and connected in three-wire quarter-bridge arrangement to Fylde 359 TA 200kHz amplifiers. The procedure adopted for positioning and static calibration of the gauges was described in detail in (5,6).

A program was developed to evaluate the signal from the straingauge using a velocity profile calculated from the striker trace. The striker trace was evaluated to calculate velocity at specific intervals, then the strain gauge trace, integrating using the calculated velocity at the corresponding interval. Corrections were incorporated for any straingauge final offset due to plastic deformation of the material in the gauged area. Full details of the techniques used are given in (7).

## CONCLUSIONS

Representative J-R curves for both geometries and test techniques are shown in figures 2 and 3, compared with the static unloading compliance results. A twofold increase in the J-R curve is observed from the static curve to the average dynamic one throughout the range of crack extension covered.

The two test methods give broadly equivalent results, although some differences are apparent. For the Chipperfield geometry, the dynamic initiation toughness is the same (≈1.7MN/m) for both thicknesses, and a twofold increase in the (dJ/da) is observed when thickness is reduced from 40mm to 20mm, with implications on the tearing modulus. Conversely, for the 3PB tests, the slope (dJ/da) remains virtually the same for the two thicknesses analysed, whereas initiation toughness is lower for the higher thickness value (1.7MN/m for B=20mm and 1.0MN/m for B=40mm). The Chipperfield method always gave higher resistance curves. This is most likely to be a result of the testing rate, since for 3PB tests a variable loading rate is unavoidable and the material in question is indeed rate sensitive. The question of rate equivalence between test methods will thus need to be considered in the drafting of a standard.

The tests with straingauges gave very similar results to fully-corrected striker load data for both Chipperfield and 3PB geometries. Thus for tests at moderate dynamic loading rates, straingauged testpieces may be used for confirmation, or if an instrumented striker is not available: at higher rates where the striker signal is unuseable, calibrated on-testpiece gauges may be the only means of obtaining a load record.

## REFERENCES

(1) Chipperfield, C.G, Journal of Testing & Evaluation, 6 (1978)
(2) MacGillivray, H.J. and Turner, C.E, Insitute of Physics Conference Series no. 102:1 (1989)
(3) Bohme, W. ASTM STP 1130 pp 92-103 (1992)
(4) Braga, L. PhD Thesis, University of London (1992)
(5) Dear, J.P. and MacGillivray, H.J. Proc ECF8 pp.169-72 Turin (1990)
(6) MacGillivray, H.J. and Cannon, D.F., ASTM STP 1130 pp161-177 (1992)
(7) Troianos, D. MSc thesis, University of London (1991)

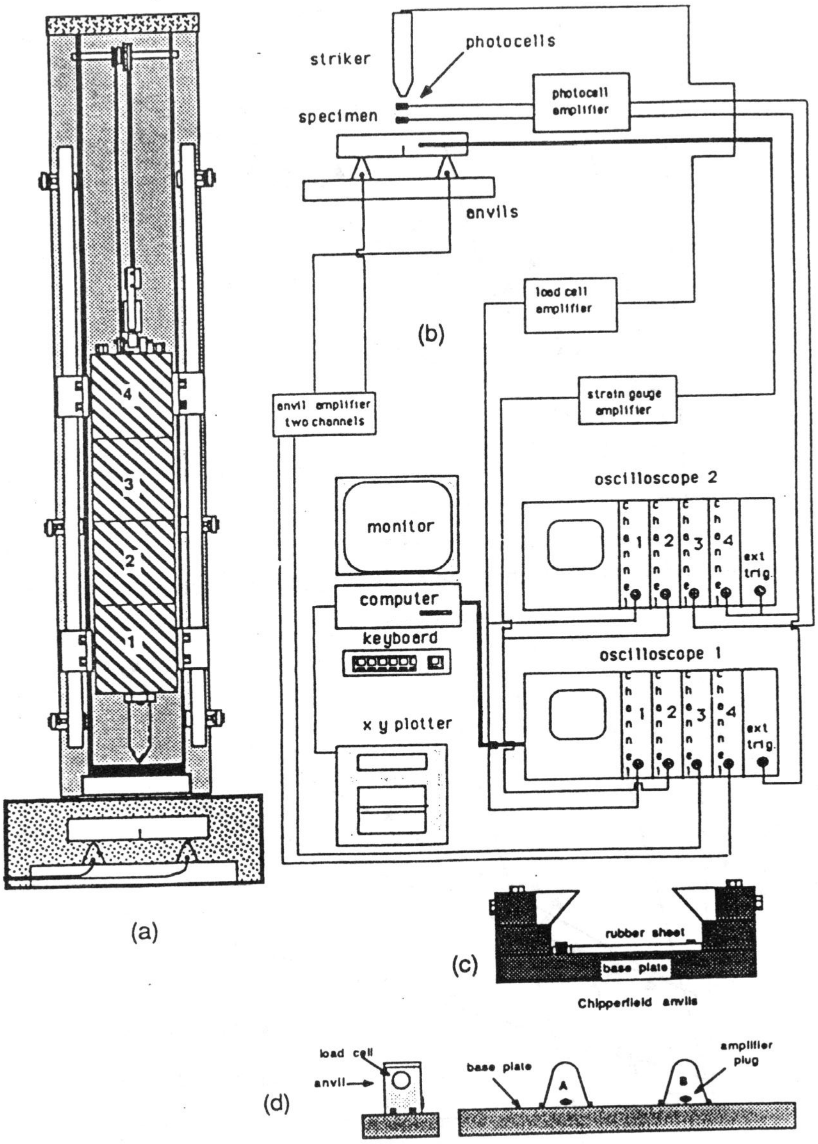
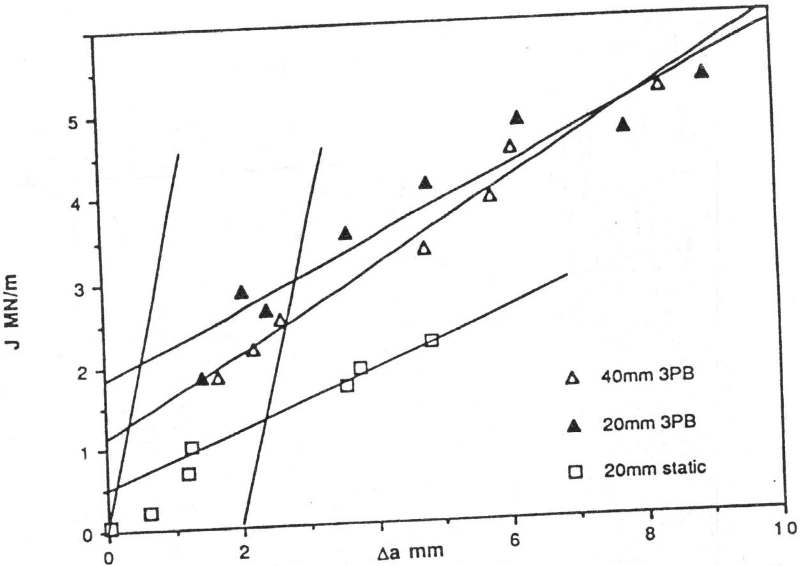
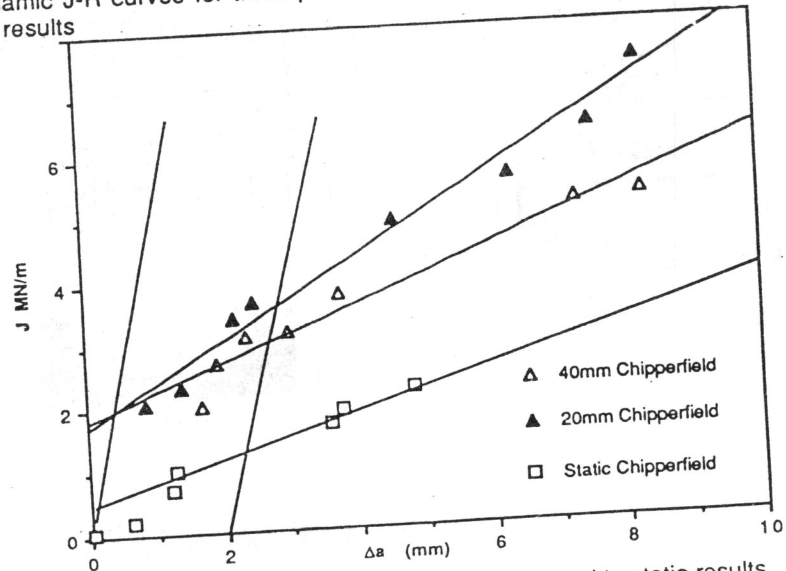


Figure 1 - Drop weight test rig showing two types of anvils and instrumentation



Dynamic J-R curves for three-point bend testpieces compared to static results



Dynamic J-R curves for Chipperfield testpieces compared to static results