THE DERIVATION OF MATERIALS PROPERTIES DATA FROM SMALL SCALE PUNCH TESTS

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The small scale punch test has been evaluated. Disc deformation behaviour has been investigated in a pressure vessel steel and its relationship with load displacement behaviour established. Empirical relationships between punch test data and uniaxial tensile data have been explored and reasonable correlations found. A punch test ductile brittle transition curve has been generated and a transition shift of 170°C obtained compared with Charpy and fracture toughness data. Comparisons with published data indicate that correlations are sensitive to specimen and test rig geometry and are generally material specific.

INTRODUCTION

Some steel pressure vessels in UK industry are approaching the end of their design lives and there is an increasing use of engineering critical assessments (ECA) as a means of demonstrating fitness for purpose and justifying extensions to life. Since the mechanical properties, including fracture toughness, of such vessels are frequently unknown, there is a requirement for the development of methods which allow the derivation of mechanical properties data without substantially damaging the vessel.

Recent developments in techniques for extracting small "boat" or "scoop" samples from structures have promoted a drive to obtain meaningful materials properties data from much smaller specimens. One important method is the small scale punch test. The procedures for deriving materials properties data, however, are not well developed and no standard test method exists. The investigation reported here was initiated to evaluate the punch test method and assess the prospects for developing relationships between punch test and conventional materials properties data.

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EXPERIMENTAL

The material used for this investigation was a fine grained ferrite - pearlite, carbon - manganese pressure vessel steel with a ferrite grain size of 14μm. The chemical analysis of the material conformed to BS 1501-161 28A. The material had a 0.2% proof strength of 334 MPa and a tensile strength of 575 MPa. Toughness was measured over the whole transition range using Charpy impact specimens and standard 20mm thick compact tension (CT) fracture toughness specimens. The fracture toughness data was analysed to derive the toughness in terms of J_{1C}.

A punch test rig was designed (Figure 1) and manufactured after a review of a range of methods employed by others. The specimens selected for this work were 3mm diameter, 0.25mm thick discs. The relationships between punch test data and tensile, Charpy and fracture toughness data were investigated.

RESULTS

Toughness Tests

The Charpy impact ductile - brittle transition data and J data are shown in Figure 2. Fully brittle lower shelf behaviour occurred at temperatures below -80°C where failure was characterised by transgranular cleavage. In the transition region, some ductile growth by microvoid coalescence (MVC) preceded fracture by cleavage. Upper shelf behaviour was characterised by 100% MVC.

Punch Load - Displacement tests

Typical punch test load displacement curves are shown in Figure 3. The curves are characterised by a linear portion (a), upto a knee (b), followed by a further linear portion with a reduced modulus (c); the curve then becomes non linear upto the maximum load (d) prior to final fracture. The relationship between the load displacement curve and the disc deformation was evaluated by terminating the individual tests at points of interest on the load displacement curve.

Punch test ductile - brittle transition data

The punch ductile-brittle transition data are shown in Figure 4. This shows the data expressed as a function of energy, obtained from an integration of the load displacement curve upto maximum load. Failure on the upper shelf is characterised by MVC. At a temperature of approximately -150°C small areas of cleavage intervene in the ductile failure process, this leads to a reduction in the displacement to failure and, even though the peak load continues to rise, the fracture energy falls.

The transition from ductile to brittle failure can also be illustrated in a plot of temperature as a function of displacement at maximum load (Figure 4). The onset of the upper shelf behaviour occurs some 170°C lower than the Charpy data.

DISCUSSION

Disc Deformation Behaviour

Region (a) of the load displacement curve is characterised by some plastic indentation of the specimen by the ball (Figure 5a), the stress on the specimen is high since the ball contact area is small. However the deformation of the specimen remote from the ball contact area appears to be predominantly elastic and unloading the specimen from a point below the knee produced no general deformation. At the knee of the load displacement curve (b) more general plastic bending of the specimen occurs (Figure 5b) as the yield zone spreads through the specimen thickness and consequently a change in modulus is observed.

Membrane stretching of the area in contact with the ball occurs (Figure 5c) with increasing load followed by specimen necking. This results in a reduction in the slope of the load displacement curve as the load carrying capacity of the specimen diminishes. The biaxial state of stress acts to promote initiation and crack propagation in both the circumferential and radial directions. Final fracture (Figure 5d) of the specimens occurs by growth of a circumferential ductile crack at the approximately 45° position and close to the maximum test load.

Punch - Tensile test relationships

The knee of the load displacement curve, where general plastic bending of the specimen appears to initiate, has been related to the yield strength, σ_Y, in the uniaxial tensile test and the maximum load prior to final fracture to the uniaxial tensile strength, σ_{TS} (1). An approximately linear relationship was found between the load at the knee, P_Y, and the yield strength of 3 alloy steels. The empirical relationship between the load P_Y and the yield stress was expressed by: $\sigma_Y = 360\ P_Y/t_o^2$ where t_o was the original specimen thickness. The results from the investigation reported here indicate a somewhat lower constant in the above equation of between 332 and 220 however a reasonable correlation was established between peak load - σ_{TS} data (1) and that reported here.

The lack of good correlations with published data was thought to be due to a combination of specimen and test geometry differences and the observation that the published correlations are empirical and therefore likely to be material dependent.

Punch - Toughness Transition Relationships

The shift in transition temperature was entirely expected since the quasi-static punch test generates much lower stresses than those associated with the dynamic, notched Charpy test or the pre-cracked fracture toughness test. The punch specimen is also less constrained and this promotes plane stress behaviour at much lower temperatures and results in upper shelf behaviour being exhibited down to -150°C.

Baik et al (2) found a 390°C shift for a phosphorus doped 3.5% nickel steel, a shift of 200°C has been reported in a 12% chromium steel (3) and shifts of between 145°C and 178°C have been obtained (4) in a range of pressure vessel steels. Correlations between the data presented here and that of other researchers is complicated by the wide range of test methods, specimen sizes and materials used.

It is clear that empirical correlations between toughness transition data and punch test transition data can be obtained however the evidence in the literature suggests that these are material specific and depend critically on specimen geometry and test method. Further work, on a range of steels, is currently in progress

CONCLUSIONS

1 The punch test disc deformation behaviour has been investigated and its relationship with load displacement data established.

2 Empirical relationships between punch test data and uniaxial tensile data have been explored and a reasonable correlation with data in the literature has been found for tensile strength. The correlation with yield strength is less satisfactory.

3 A shift of 170°C in the punch test transition compared with the Charpy test was obtained. A comparison with published data indicates that transition shifts are sensitive to specimen and test rig geometry and are material specific.

REFERENCES

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(4) Kohse G., Ames M., Harling O.K. Journ. of Nuclear Mat. 141 (1986) 513-517.

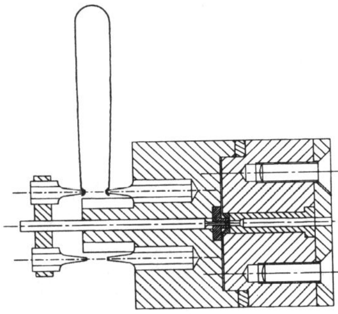


Figure 1 The punch test rig

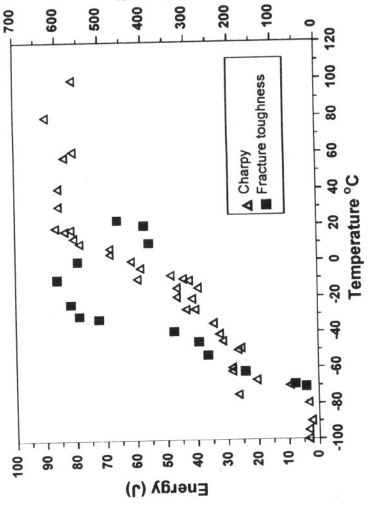


Figure 2 Toughness Transition Data

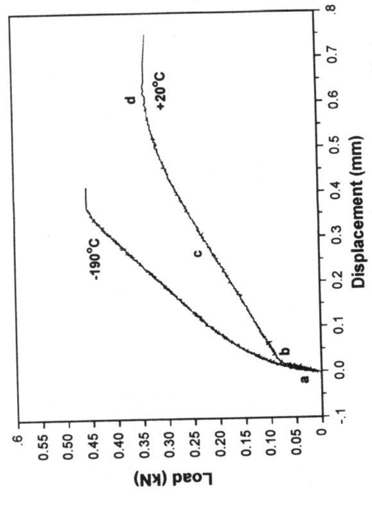


Figure 3 Punch Load Displacement Data

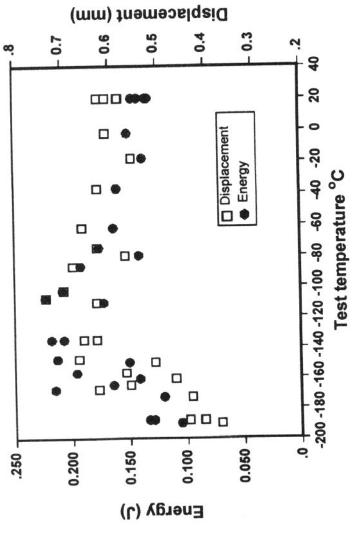
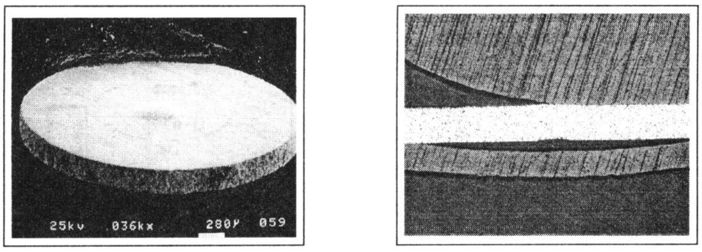
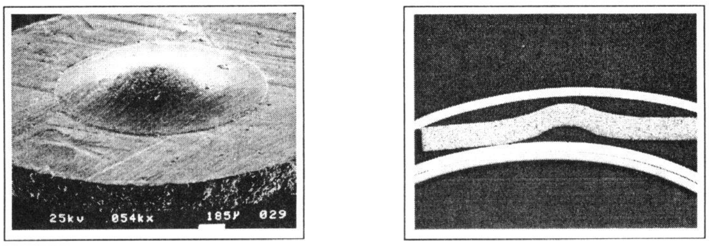


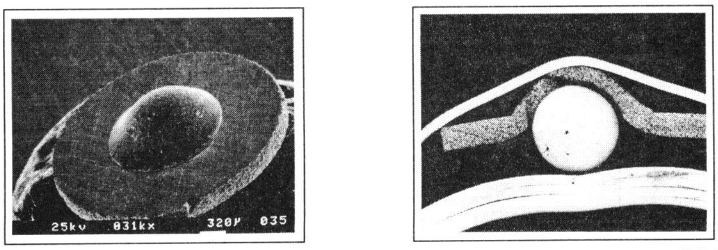
Figure 4 Punch Transition Data



a) Disc Deformation below the knee x50



b) Disc Deformation above the knee x37.5



c) Disc Deformation below max. load x37.5

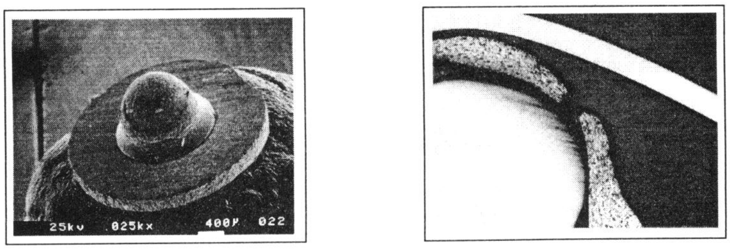


Figure 5 d) Disc Deformation at maximum load x100