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TITLE

JID TESTING OF AN HY 80 STEEL WELDMENT

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J_{Id} Testing of an HY 80 Steel Weldment

by K.D. MacKay[1] and Dr. J.R. Matthews[2]

[1] Martec Limited
Suite 400, 1888 Brunswick St.
Halifax, Nova Scotia, Canada, B3J 3J8

[2] Defence Research Establishment Atlantic,
Dockyard Laboratory, FMO Halifax,
Halifax, Nova Scotia, Canada, B3K 2X0

ABSTRACT

Evaluation of the dynamic elastic-plastic toughness properties of very tough structural steels is an expensive and complicated activity. For military purposes, the dynamic tear test and explosion bulge test have been used in the absence of a simple dynamic elastic-plastic toughness test. DREA has developed a simplified multiple specimen method of determining J_{Id}, which uses a standard drop, tower without instrumentation. A blunting resistance curve is generated, typically from blunting up to complete fracture, by impacting specimens using progressively larger weights and small changes in drop height. The lack of need for instrumentation puts the use of this test into the financial range of many more organisations.

Specific test results will be given for HY 80 welds, prepared at DRA Dunfermline, tested at -5°C.

INTRODUCTION

The Materials Group at DREA have been developing a test method to determine the dynamic elastic-plastic fracture toughness of materials used in naval applications. The ideal test method would incorporate the following features:

- inexpensive
- simple to perform
- little interpretation of data required to generate the toughness value
- test specimens sized to be structurally relevant
- test easily performed at low temperatures

These features would make it possible for the test to be performed at a larger number of facilities and make the test useful as a quality control test.

The elastic-plastic conditions in which the test method is to apply are defined by the central portion of the materials transition curve as shown in Figure 1. At the lower portion of the curve, the materials behaviour can be described by linear-elastic fracture mechanics using a parameter such as K. The upper portion of the curve is dominated by plasticity where failure occurs by plastic collapse and toughness can be described by $\hat{k}$ (flow stress in shear). The central portion of the curve defines the temperature range where elastic-plastic toughness parameters are useful in describing the material behaviour and a toughness parameter such as the J integral can be applied.

BACKGROUND

Static Methods

There are a number of standard test methods for determining the J_{Ic} under quasi-static loading. ASTM standards E813 and E1737 [1] describe three different methods which can be used to determine J_{Ic}. The first method to be used was a multiple specimen technique in which nearly identical specimens were prepared. A specimen is loaded to generate a desired amount of crack extension during which load and displacement are recorded. The area under the load displacement curve is used to determine the energy, U, required to extend the crack. The value of J for each specimen is found using the equation

$$J=2U/Bb_o \qquad (1)$$

where B is the specimen thickness and b_o is the size of the original uncracked ligament. The crack is marked after the test by fatiguing or heat tinting and broken open so that the original crack length and the amount of crack extension can be measured. The J-crack extension data pairs are plotted and J_{Ic} is determined by the intersection of a power law fit through the data and an offset blunting line as shown in Figure 2, provided that validity criteria are met.

The second method described by the ASTM standards is a single specimen technique which uses unloading compliance to measure crack length. The specimen is loaded with load and displacement recorded. At various intervals in the test the loading is paused and the specimen is partially unloaded and reloaded to generate an unloading segment in the load displacement record as shown in Figure 3. The slope of the unloading segments are used with a compliance function to determine the crack length at each unloading segment. The value of J is also determined at each unloading segment in terms of its elastic and plastic components. The elastic component is determined from the load, crack length and the specimen dimension and the plastic component is determine by

$$J_{pl}=2U/Bb_o \qquad (2)$$

where U is defined by the shaded region under the load displacement curve as depicted in Figure 3. The J-crack extension data pairs at each unloading are plotted and treated in the same manner as the multiple specimen data to determine J_{Ic}.

The third technique described by ASTM E1737 uses electric potential to determine crack size while a single specimen is loaded. A direct current is passed through the specimen while the voltage across the crack is monitored. As the crack grows the current field in the specimen is altered which is indicated by a change in the voltage reading. Crack length is determined from the voltage readings using an experimental or analytical calibration curve. The value of J is determined from the load displacement record in a similar manner as with the unloading compliance method. The J-crack extension data pairs are plotted to determine J_{Ic} as with the first two methods.

Dynamic Methods

The unloading compliance technique is not suitable for a dynamic test because it is undesirable to unload the specimen during the test (pausing to unload the specimen even briefly would affect any time dependant mechanisms and thus reduce the significance of any rate effects).

The electric potential technique has been used to determine the dynamic fracture toughness of materials. However, the complexity and expense of the equipment required to perform the test is significant. The success of the method is dependant on the expertise of the personnel performing the test as there are a number of factors which can produce errors in the measurement including thermal drift, placement of the current input and voltage measurement electrodes, selection of input current magnitude, and electrical isolation of the specimen. Precautions must also be taken to ensure that low level voltage readings are not obscured by induced EMF and improper grounding of equipment.

A number of techniques have been used to determine the crack length during dynamic fracture. Crack growth has been monitored using grids bonded to the surface of the specimen where the crack extension is given by the breakage of the grid elements or the resistance change of the grid. High speed photography has also been used to measure crack growth during dynamic fracture. The difficulty of both these methods is that they are only capable of measuring the crack length at the surface which may not accurately reflect through thickness crack propagation. High speed photography is also expensive due to the equipment required and the large number of photographs to be processed.

Measuring load and displacement during a dynamic test increases the cost of the equipment required to perform the test. Inertial effects can create difficulties in the load and displacement records obtained in dynamic testing. Impact of the specimen with a striker creates vibrations in the specimen which appear as oscillations in the load and displacement records. While some work has been performed on the use of damping the oscillation using absorbers [2-4] there has been concern that the specimen velocity is not constant as the crack grows (due to over damping). Others have used smoothing techniques to remove oscillations from the data record however data smoothing can create errors due to skewing of the data [3, 4].

EXPERIMENTAL (DREA J_{50} METHOD)

Dynamic elastic-plastic fracture toughness tests were performed using the J_{50} test method developed at DREA. The technique uses a number of identically prepared fatigue precracked single edge notch bend (SEN(B)) specimens. The specimens were impacted using a drop tower to generate a different amount of crack extension in each specimen. Crack length and crack extension were measured by marking the crack by post-test fatigue or heat tinting and breaking the specimen to reveal the fracture surface. The 9 point measurement technique, described in ASTM E813 and E1737 [1], was used to measure the original and final crack lengths.

The value of J for each specimen was determined using Equation 1 however in this case the energy term, U, was equated with the potential energy stored in the crosshead of the drop tower:

$$U = w \cdot h \qquad (3)$$

where w is the weight of the crosshead and h is the height of the striker above the specimen. The energy applied to each specimen was adjusted by varying either the weight of the crosshead and/or the height from which the crosshead was dropped.

The J-crack extension data pair from each specimen was plotted to give a dynamic J-resistance curve. The intersection of a data fit through the points and an offset blunting line gives the value of J_{Id}, the dynamic elastic plastic fracture toughness of the material.

The J_{50} test method was used determine the dynamic fracture toughness of an HY 80 weldment that was prepared at DRA Dunfermline [5]. Two SEN(B) specimen configurations were used; one with B=25 mm and W=41 mm and a second with B=75 mm and W=41 mm. Shallow and deep notch specimens were prepared for both specimen configurations. The notch depths for the 25 mm and 75 mm thick specimens are given in Tables 1 and 2 respectively. The dynamic tear transition curves for both shallow notch and deep notch specimens are given in Figure 4. All specimens were tested at -5°C.

RESULTS

The results of the J_{50} tests are given in Tables 1 and 2 for the 25 mm and 75 mm thick specimens respectively. The results are plotted in Figures 5 and 6.

Estimates of the J_{Id} for the 25 mm thick specimens are 1370 kJ/m^2 and 200 kJ/m^2 for the shallow and deep notch specimens respectively. The 75 mm specimens gave J_{Id} values of approximately 400 kJ/m^2 and 40 kJ/m^2 for the shallow and the deep notch specimens. It should be noted that the J_{Id} values given here are approximate due to the limited number of data points.

DISCUSSION

The J_{50} technique offers several advantages over other dynamic test methods. Load, displacement and crack length measurement during the test are not required which reduces the equipment required along with the associated cost and complexity. Low temperature tests are easily performed by cooling the specimen before placing it in the drop tower. Structurally relevant full thickness specimens up to 75 mm have been tested. The calculations to generate the dynamic J-resistance curve are simple and the determination of J_{Id} requires limited data analysis.

One aspect of the J_{50} test which should be noted is that the energy applied to the specimen may be adjusted from specimen to specimen by increasing the drop height and thus the impact velocity is not constant. However the velocity range for the test is typically in the range of 1-3 m/s and errors associated with velocity changes over this range are expected to be minimal. Figure 7 shows data for HSLA 80 steel which was tested over a large range of velocities at two temperatures [6]. Note that the toughness change over the J_{50} velocity range, indicated by the shaded region in Figure 7, is minimal.

New test method

While the J_{50} test method provides a simple method of performing dynamic elastic plastic fracture testing there are some aspects of the test that could be improved. Being a multiple specimen test requires several specimens to be prepared by fatigue precracking for each temperature at which J_{Id} is required. The time to prepare the specimens could be reduced by either replacing the fatigue crack with another notch or by reducing the number of specimens.

A simple test for quality control purposes may be derived from the J_{50} method. The basis of the test would be to define an allowable amount of crack extension when a specimen is impacted. The specimen design and equipment requirements would be the same as with the J_{50} test. Test parameters of crosshead weight, drop height, specimen dimensions, and crack length would define the velocity and the applied J. The drop height would be selected to give a velocity that the structure is expected to experience (for example 1-4 m/s is representative of an explosion). The data from these tests can be plotted as crack extension vs temperature which would be expected to have the form of Figure 8 over the materials transition range.

The amount of allowable crack extension can be based on the desired dynamic J-resistance curve for the material. If the structure design requires that the structure withstand a certain J value at a specified temperature then the J-resistance curve for that temperature would define the amount of crack extension that would be acceptable. Since each specimen will generate a J-crack extension data pair it would also be possible to compare the material to a J-resistance curve by plotting the point on the curve. If the data point falls below the desired J-resistance curve then the material toughness is not acceptable. If the data point is on or above the J-resistance curve then the material meets or exceeds the desired material specifications.

The simple test described above has the advantage over the J_{50} test in that only one specimen is needed at each temperature. Specifying a drop height for all tests eliminates any concern over velocity change effects.

CONCLUSIONS

DREA has developed a simple multiple specimen technique to determine the dynamic elastic plastic fracture toughness of structural steels which offers several advantages over conventional test methods in that it is easy to perform, no instrumentation required, little data interpretation required, and structurally relevant specimens are used. The test method has been used to determine the J_{Id} of an HY80 weldment using both 25 mm and 75 mm thick specimens.

A simple dynamic test for quality control purposes has been proposed which, with further development, may soon be available.

REFERENCES

[1] "ASTM Annual Book of Standards", Vol. 3.01, Philadelphia, PA, 1996.

[2] K.J. KarisAllen, J. Morrison, "Mechanical Reduction of Inertially Generated Effects in Single-Edge Notch Bend (SENB) Specimens Subjected to Impact Loading", *Rapid Load Fracture Testing*, ASTM STP 1130, R, Chona and W.R. Corwin, Eds., ASTM, Philadelphia, 1991 pp. 76-91.

[3] J.A. Joyce and E.M. Hackett, "Dynamic J-R curve Testing of a High Strength Steel Using the Key Curve and Multispecimen Techniques", *Fracture Mechanics: Seventeenth Volume*, ASTM STP 905, J.H. Underwood, R. Chait, C.W. Smith, D.P. Wilhem, W.A. Andrews, and J.C. Newman, Eds., ASTM, Philadelphia, 1986, pp. 741-774.

[4] J.A. Joyce and E.M. Hackett, "An Advanced Procedure for J-R Curve Testing using a Drop Tower", *Nonlinear Fracture Mechanics: Volume I-Tine-Dependant Fracture*, ASTM STP 995, A. Saxena, J.D. Landes, and J.L. Bassani, Eds., ASTM, Philadelphia, 1989, pp. 298-317.

[5] J.D.G. Sumpter, "Production of Q1N Welded Panels for TTCP Operating Assignment on Fracture Control Technology", DRA TM (AWMS) 93217, May, 1993.

[6] N.B. Bassim, J.R. Matthews, and C.V. Hyatt, "Evaluation of Fracture Toughness of HSLA80 Steel at High Loading Rates Using Stretch Zone Measurements", *Engineering Fracture Mechanics*, Vol. 43, No. 2, 1992, pp. 297-303.

Table 1: J_{50} test data and results, B=25 mm

Specimen	Temp. (°C)	a_o (mm)	Height (m)	Weight (N)	Velocity (m/s)	J (kJ/m^2)	Δa (mm)
UK36	-5	5.84	0.114	7993	1.50	2046	22.93
UK25	-5	5.87	0.076	7993	1.22	1365	0.19
UK22	-5	6.40	0.076	2700	1.22	468	0.12
UK7	-5	20.55	0.038	2700	0.86	396	5.09
UK5	-5	20.43	0.064	2700	1.12	656	5.44
UK3	-5	20.10	0.076	2700	1.22	775	6.82
UK18	-5	20.80	0.076	2700	1.22	802	15.12

Table 2: J_{50} test data and results, B=75 mm

Specimen	Temp. (°C)	a_o (mm)	Height (m)	Weight (N)	Velocity (m/s)	J (kJ/m^2)	Δa (mm)
UK42	-5	9.62	0.190	2700	1.93	407	0.65
UK14	-5	9.86	0.305	2700	2.45	656	18.83
UK28	-5	11.17	0.381	2700	2.73	854	27.27
UK12	-5	21.84	0.038	2700	0.86	129	3.92
UK40	-5	21.58	0.076	2700	1.22	254	8.44
UK13	-5	22.25	0.114	2700	1.50	394	15.2
UK27	-5	22.76	0.229	2700	2.12	547	20.04

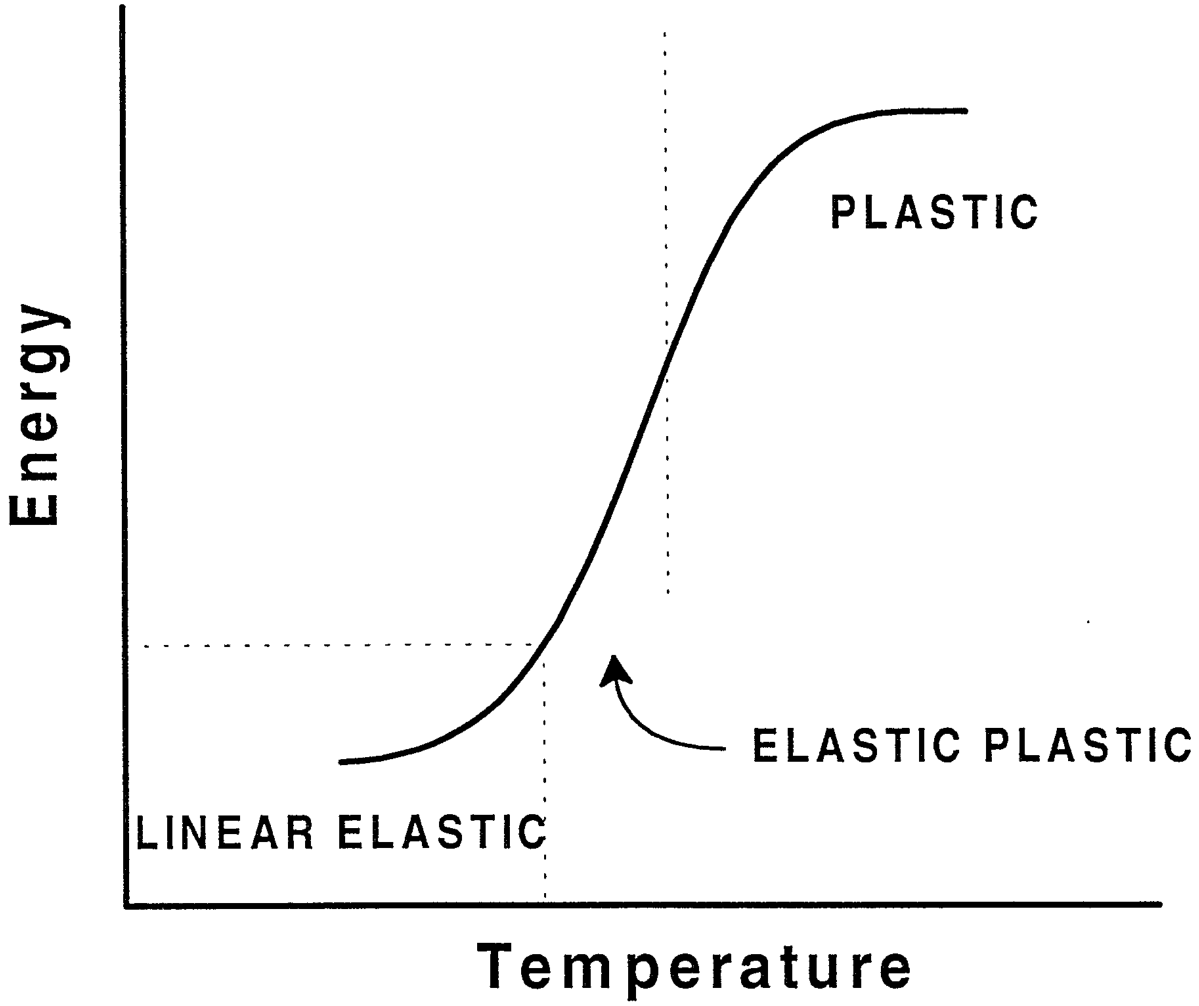

FIGURE 1.: A sketch indicating the fracture behaviour of a material over its transition range.

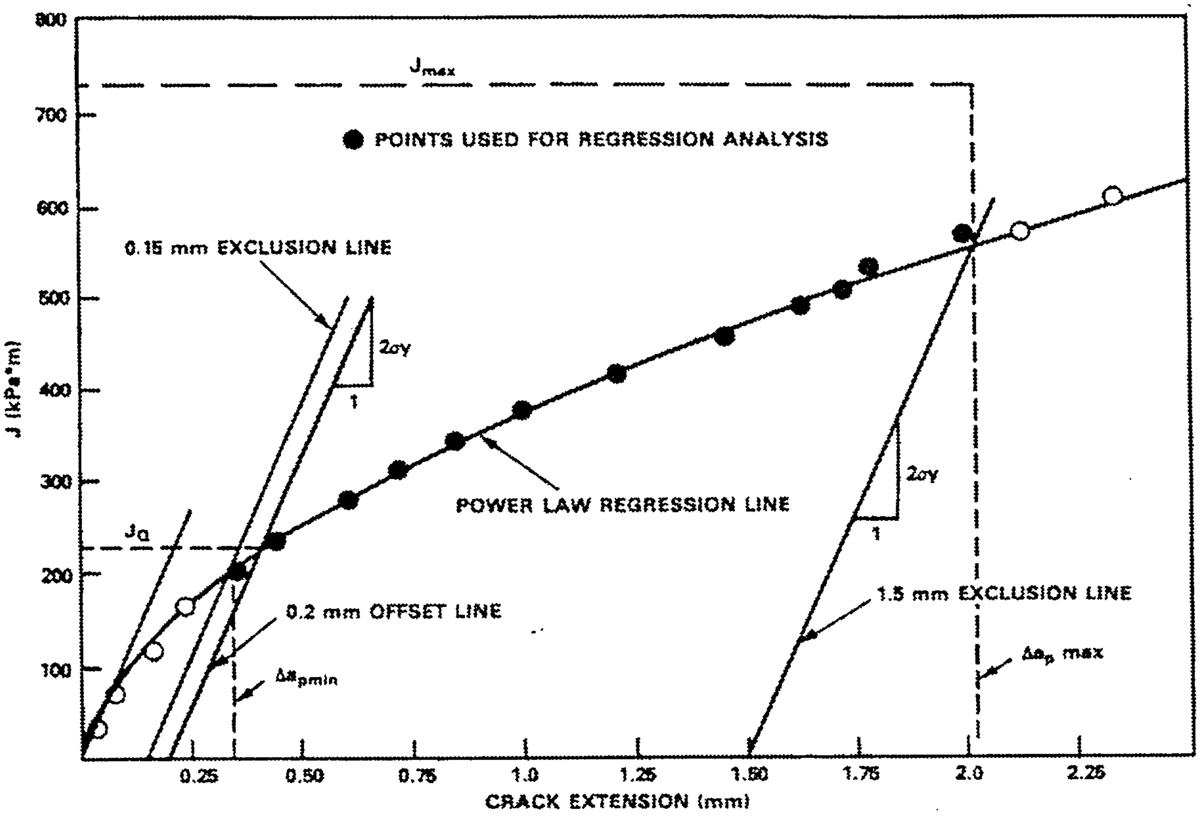

FIGURE 2.: A typical J-crack growth resistance curve [1].

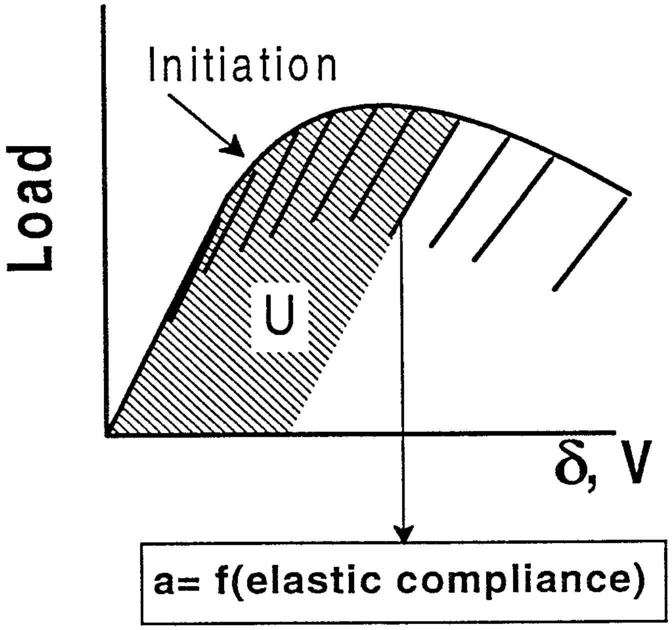

FIGURE 3.: Unloading compliance method load-displacement record.

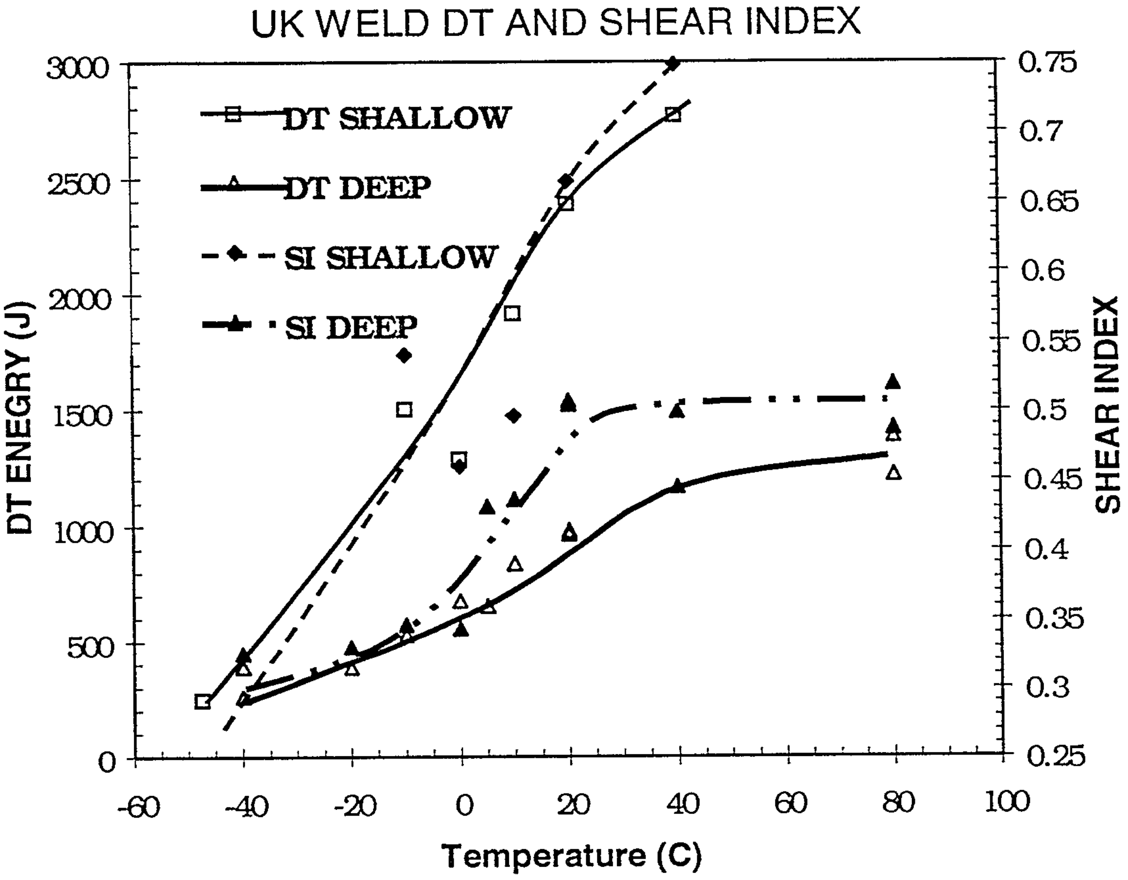

FIGURE 4.: Dynamic Tear and Shear Index transition curves for the HY 80 weldment for both deep notch and shallow notch specimens.

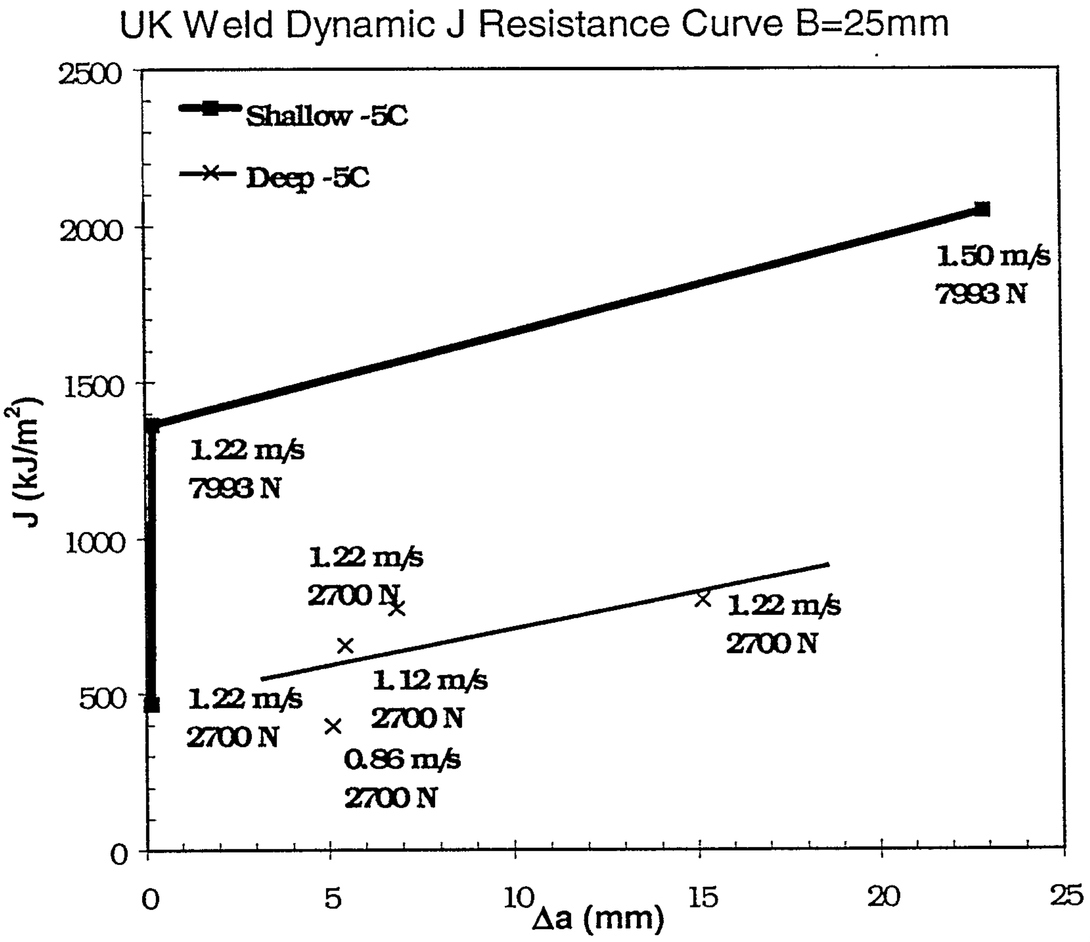

FIGURE 5.: HY 80 weldment dynamic J-resistance curve for 25 mm thick specimens.

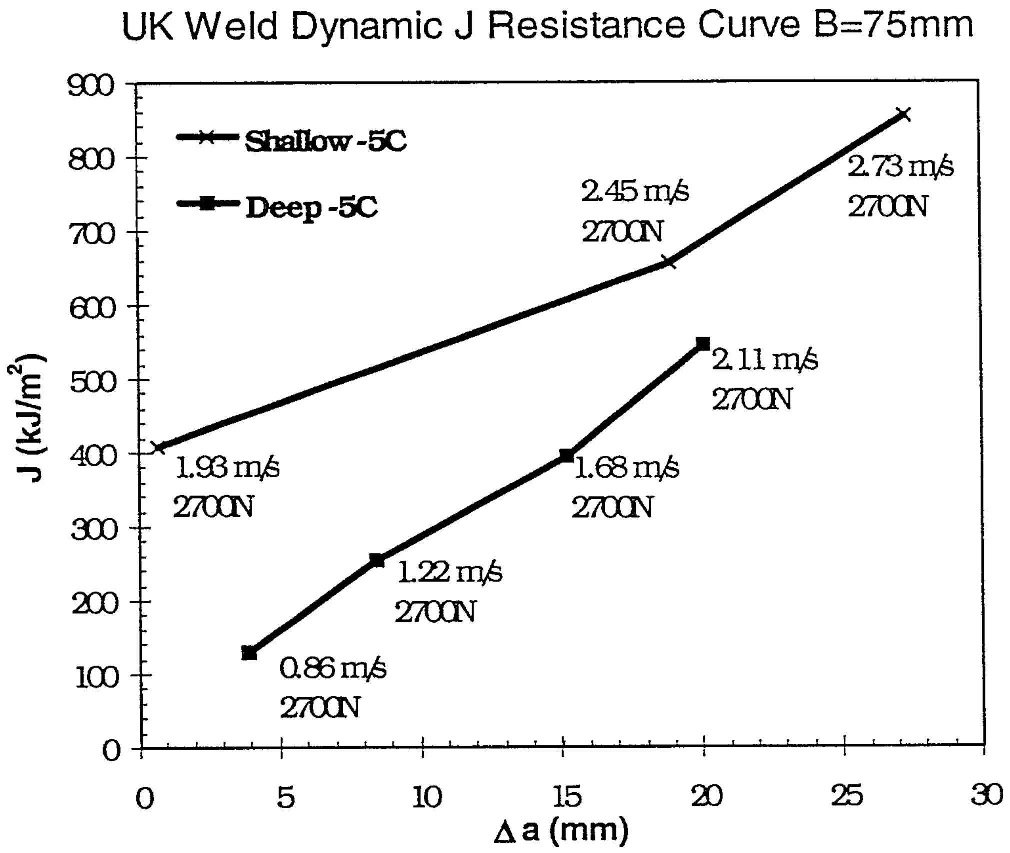

FIGURE 6.: HY 80 weldment dynamic J-resistance curve for 75 mm thick specimens.

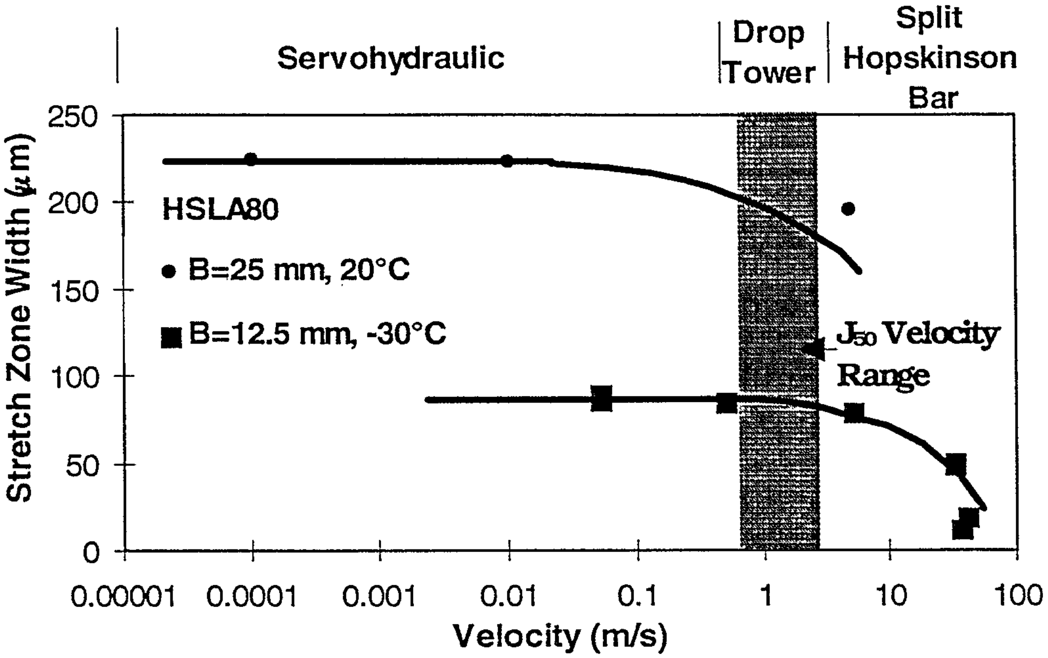

FIGURE 7: The affect of velocity on toughness [6].

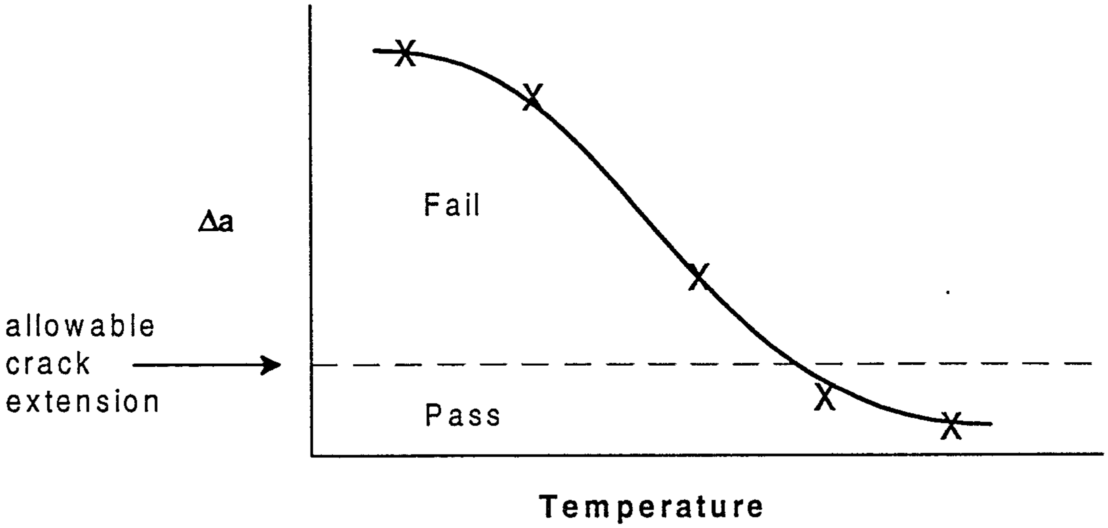

FIGURE 8.: Expected results from proposed test method. Only one specimen is required to produce each data point.

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