TREATMENT OF MIS-MATCH WELD DATA

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Studies on A533B-1 ferritic pressure vessel steel have indicated that both strength under-matching and over-matching of materials modifies crack growth resistance curves compared with the relevant base-line materials. If the analysis procedures for homogenous materials are applied to test results then strength over-matching causes an apparent elevation of the J-R curve, and under-matching a lowering of the J-R curve. These differences in observed behaviour are reduced if the appropriate strength mis-match plastic eta factors are used in the determination of the experimental J-integral values.

INTRODUCTION

Experimentally and analytically there is a need to know how fracture toughness and resistance to crack growth curves are modified as a function of strength mismatch in weldments. It is also important to know how far the treatment of experimental data using standardised test and analysis procedures for homogenous material can be exploited for situations where welds are present in a structure/ specimen. This paper provides experimental results from tests undertaken on a series of strength mis-matched specimens in order to examine the influence of strength mis-match on the J-Resistance curves. Unless stated otherwise the fracture toughness parameters have been calculated using standard formulae for homogenous materials as given in ESIS procedure P2-91(1).

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EXPERIMENTAL

A533B-1 forged plates were heat treated to provide high and low yield and ultimate tensile strength values. 15mm wide sections of these plates were electron beam (EB) welded to larger sections to give under- and over-matched weldments. A stress relief heat treatment of 19 hours at 590°C was applied to the weldments prior to machining of the specimens in order to reduce the residual stress introduced by the EB welding process. Plates and weldments were designated as follows

M1	Material 1: High yield strength (740MPa)
M3	Material 3: Low yield strength (500MPa)
1E3E1	Material 3 EB welded between Material 1 plates (under-matched)
3E1E3	Material 1 EB welded between Material 3 plates (over-matched)

Single Edge Notched Bend (SENB) fracture toughness specimens (B=25mm and W=40mm) were machined with the notch in the middle of the plate material or weldment. The specimens were fatigue pre-cracked to a nominal crack length to width ratio (a/W) of 0.65 at an R-ratio of 0.1 using a maximum stress intensity factor, K_{max}, of less than 25MPa√m. Specimens were subsequently side grooved 20% (in total) and tested using the unloading compliance technique with an a.c. potential drop technique also providing independent estimates of ductile crack extension. Testing and analyses of data were carried out to the requirements of ESIS P2-91 (1). Tensile data were obtained from 5mm diameter specimens tested to BS EN 10-002 (2). All specimens were tested at an ambient temperature of 21°C ±3°.

Duplicate tests were made on each of the homogenous materials, and triplicate tests made on each of the strength mis-matched weldments. The J-Δa data from these tests are summarised in Figure 1. There was little scatter associated with testing any given group of specimens. This figure indicates that the J-R curve data produced from both the under- and over-matched welds are in close agreement with each other and are similar to those produced for the homogenous high strength material M1. Only at levels of crack extension (Δa) greater than approximately 1mm do the J-R curves start to deviate from the J-R curve for the high strength M1 plate material.

DISCUSSION

It should be noted that for the determination of the J-R curves shown in Figure 1 the plastic eta factor η_p for homogenous material was used, that is η_p =2 for SENB specimens. However, there are plastic eta factors available from the work of Joch et al (reference 3) which are applicable to the under- and over-matched SENB weld specimens tested here. These mis-match plastic eta factors (η_p) are based on slip line field analyses and are related to the width of the weld (2h) and the ligament ahead of the crack tip (b).

Figure 2, taken from reference 3, provides η_p factors as a function of half-weld width to ligament ratio (h/b) and weld yield strength to base material mis-match ratio. It should be noted that for homogenous materials η_p = 2 for all h/b ratios. For under-matched specimens, η_p is greater than 2 for h/b < 0.33, and, for over-matched specimens η_p is less than 2 for h/b <0.45.

Overmatched condition (3E1E3) [Figure 3]
The strength mis-match ratio for specimens 3E1E3 is 1.48. The width between the Heat Affected Zones of the EB welds was 2h = 7mm. At an a/W of 0.65 and an h/b ratio of 0.25, then η_p is 1.8. Using this value of η_p to determine J, in Figure 3, gives a reduction in the J-R data particularly at the higher levels of crack extension compared with the J-R data evaluation for η_p =2. From Figure 3 it can be seen that there is generally good agreement between both η_p=2 and η_p =1.8 data sets near the initiation of ductile tearing (at Δa = 0.2mm). However, the η_p=1.8 data are in better agreement with data from the homogenous material M1 at levels of crack extension greater than 1mm.

Under-matched condition (1E3E1) [Figure 4]
The strength mis-match ratio for specimens 1E3E1 is 0.67. For a 2h value of 7mm η_p is 2.3 (Figure 2). The use of this eta factor in the J expression results in an increase in the J-R curves towards that of the homogenous M3 material. However, it still remains below the M3 J-R curve (Figure 4). Using a value of 2h = 5mm (as observed on one of the metallographic slices of 1E3E1 material) provides a values of h/b = 0.178 and η_p=2.6. This improves the situation further, but the data still lie below the Material 3 data. This is probably due to the high yield stress associated with the Heat Affected Zone (HAZ). No tensile data are available for the electron beam weld or HAZ, however, an estimate of 920MPa was obtained from hardness measurements.

CONCLUSIONS

An evaluation of the crack growth fracture resistance behaviour of mis-match welded joints has shown that:

1. J-R curves -Over-matched specimens

Using a conventional J analysis for homogenous materials, then over-matched specimens (1.48 strength mis-match) show an increase in J-R curve behaviour above that for the equivalent homogenous base materials at the higher levels of crack extension. The use of a mis-match plastic eta factor (η_p), appropriate to the level of mis-match shown, for calculating the J-integral shows better agreement with the homogenous base material data.

2. J-R curves -Under-matched specimens

Similarly, under-matched specimens (0.67 strength mis-match) have shown a lowering of the J-R curve behaviour compared with the homogenous base material. The use of a mis-match η_p value to evaluate the J-integral increases the slope of the J-R curve, but still falls below that for the homogenous base material.

ACKNOWLEDGEMENTS

This work was carried out as part of the R6 programme sponsored by Nuclear Electric plc, AEA Technology, British Nuclear Fuels Ltd and Scottish Nuclear Ltd, and the paper is published with permission of AEA Technology and Nuclear Electric plc.

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3. J Joch, R A Ainsworth, T H Hyde and B K Neale 'Fracture parameters and fracture assessment for welded structures" International Symposium on Mis-matching of welds, Reinstorf, Germany , May 26-28, 1993.

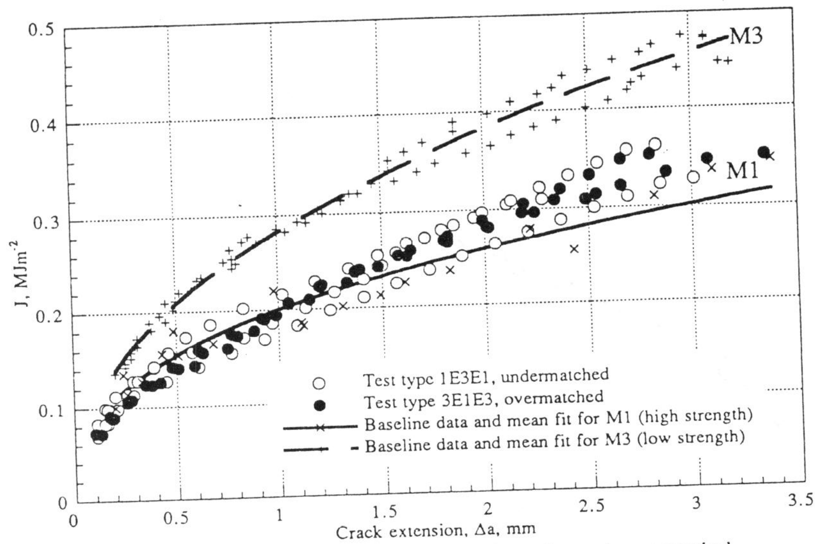

Figure 1. Fracture toughness J-Δa for under- and over-matched material compared with baseline data

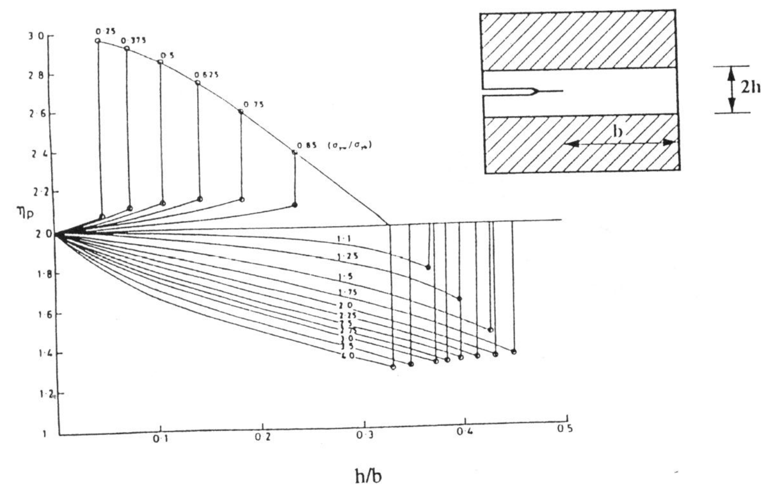

Figure 2 Variation of η_p with h/b and σ_{yw}/σ_{yb}

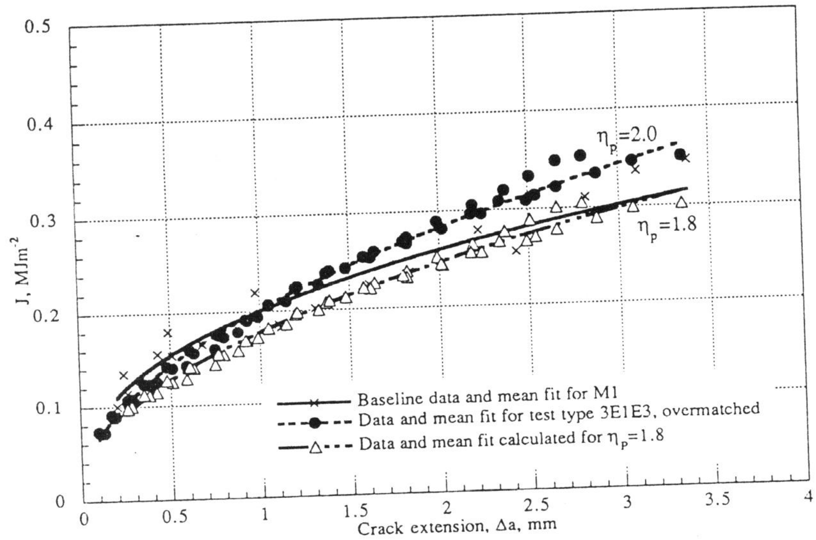

Figure 3. Influence of η_p on J-Δa data for over-matched 3E1E3 material

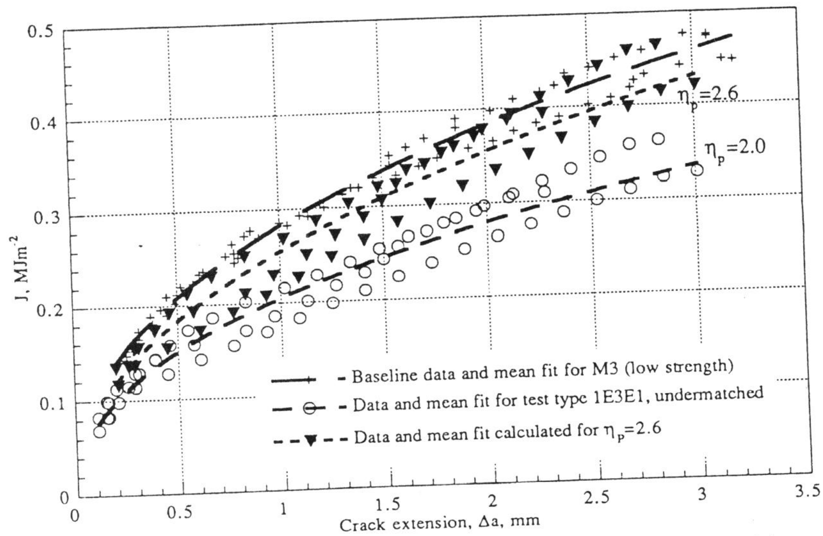

Figure 4. Influence of η_p on J-Δa data for undermatched 1E3E1 material