THE TREATMENT OF FRACTURE TOUGHNESS DATA IN THE TRANSITION REGIME

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Methods have been developed for the treatment of fracture toughness data in the transition regime. In the simplified treatment given here, the fracture toughness is evaluated at, or close to, the onset of stable tearing prior to unstable fracture using parameters determined according to the ESIS Procedure. The approach enables the entire range from brittle to fully ductile material behaviour to be described with initiation parameters irrespective of the fracture mechanism.

INTRODUCTION

The European Structural Integrity Society (ESIS) have issued a Procedure for determining the fracture behaviour of materials (1) which covers the range from brittle through to fully ductile material behaviour. In the transition regime, the ESIS Procedure uses J_c and J_u to describe the fracture behaviour. If, prior to unstable fracture, crack growth is less than 0.2 mm, then the fracture resistance is designated J_c. If crack growth exceeds 0.2 mm, it is designated J_u. The use of J_u gives rise to problems in assessment procedures based on initiation fracture parameters.

In the brittle, ductile and lower transition regimes (1), the fracture parameters K_{IC}, $J_{0.2}$ and J_c, respectively, are applicable to the onset of crack initiation. However, in the upper transition regime the parameter J_u is a function of the amount of stable crack growth occurring prior to unstable cleavage fracture, Δa_c. The amount of stable crack growth contributes to scatter of the fracture toughness data in the transition regime.

Moskovic and Neale (2) have developed two approaches for assessing fracture toughness data in the transition regime. The simplified method presented here enables fracture toughness to be evaluated at, or close to, the onset of stable tearing prior to unstable fracture. Thus, the complete range from brittle through to fully ductile material

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behaviour can be described by initiation fracture parameters suitable for structural integrity assessments. The method is described in the following section.

METHOD

The method is illustrated schematically in Figure 1. A graph of the fracture resistance, J, versus stable tearing, Δa_c, prior to unstable fracture, is plotted as a function of temperature. A best fit straight line of slope dJ/da is drawn through the J-Δa_c data points. The slope is then used to estimate the fracture resistance, $J_{u/0.2}$, at the onset of stable tearing from the equation:

$$J_{u/0.2} = J_u - (\Delta a_c - 0.2)\ dJ/da \qquad (1)$$

for all the J_u data points for which Δa_c exceeds 0.2 mm independent of specimen thickness. It should be noted that the mean value of dJ/da is used to evaluate $J_{u/0.2}$ and no allowance is made for scatter in the J-Δa_c data.

The fracture toughness K_c, $K_{u/0.2}$ or $K_{0.2}$ are obtained from J_c, $J_{u/0.2}$ or $J_{0.2}$, respectively, using

$$K = \sqrt{\frac{EJ}{1-\nu^2}} \qquad (2)$$

where E is Young's modulus and ν is Poisson's ratio.

In order to simplify the analysis a best fit curve is determined for the fracture toughness data using the equation:

$$K = A_o \exp(A_1 T) \qquad for\ T \leq T_1 \qquad (3)$$

$$= A_2 + A_3 T \qquad for\ T > T_1 \qquad (4)$$

where the coefficients A_o, A_1, A_2 and A_3 are evaluated using a statistical analysis program. T_1 is the temperature appropriate to the onset of the ductile regime for which the $K_{0.2}$ data are applicable. The curve represents the mean initiation fracture toughness throughout the temperature range independent of the fracture mechanism. It should be noted that the fit to the data given by equation (3) underestimates the steepness of the transition curve as the upper shelf is approached. A more detailed fit and a method of defining the transition temperature, based on fracture mechanics, is given in (2).

RESULTS

Figure 2 shows all the fracture toughness data from the US Heavy Section Steel Irradiation Program 5th Series for unirradiated submerged arc weld metal obtained using compact specimens in the thickness range from 25.4 to 203.2mm. The same data analysed according to the method described in the previous section are shown in Figure 3. $J_{u/0.2}$ was evaluated for only 32 of the original 153 data points, equation (1). The slopes of the best fit lines decreased and the intercepts increased with increasing temperature over the range -30 to 20°C independent of specimen thickness. Comparing Figures 2 and 3 indicates there is a marked reduction in scatter and significant improvement in the 95% confidence limits as a result of using the method described in the previous section.

To further illustrate the method, data have been obtained, Figure 4, for an A508 Class 3 forging extending into the ductile regime. In the transition regime, when the stable tearing prior to unstable fracture was less than 0.2mm, the fracture toughness was derived from J_c(1). At larger tearing, the fracture toughness was derived from $J_{0.2}$(3) using the J-Δa curve generated prior to unstable fracture. $J_{0.2}$ was also used to estimate the initiation fracture toughness in the ductile regime. Equation (3) was used to determine the best fit curve through the data. This curve represents the mean initiation fracture toughness of the material irrespective of the fracture mechanism.

The curve shown in Figure 4 represents initiation toughness irrespective of the fracture mechanism. Consequently, it cannot be used to define the transition from one mechanism to another. A more detailed statistical treatment is given by Moskovic and Neale (2) which reproduces the results of the method given in this paper and also describes the fracture toughness at cleavage. The more detailed statistical treatment is recommended where information on the cleavage to ductile transition temperature is needed in addition to the initiation fracture toughness.

CONCLUDING REMARKS

A simplified method has been presented which enables fracture toughness in the transition regime to be evaluated at, or close to, the onset of stable tearing. The onset of stable tearing is defined as the value of the fracture resistance, $J_{u/0.2}$, at 0.2mm crack growth. The use of 0.2mm is consistent with the definition of $J_{0.2}$ in the ductile regime and with the change between J_c and J_u in the transition regime (1). Replacing J_u with $J_{u/0.2}$, equation (1), means that the entire range from brittle through to fully ductile material behaviour can be described with initiation parameters irrespective of the fracture mechanism. The advantages of this approach are that scatter is significantly reduced, Figure 2 and 3, and that a single curve can be used to describe fracture toughness consistently throughout the range of material behaviour.

REFERENCES

(1) ESIS P2-91D, ESIS Procedure for Determining the Fracture Behaviour of Materials, Second Draft, May 1991.

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(3) Neale, B K, et al, A Procedure for the Determination of the Fracture Resistance of Ductile Steels, 20(3), 1985, 155-179.

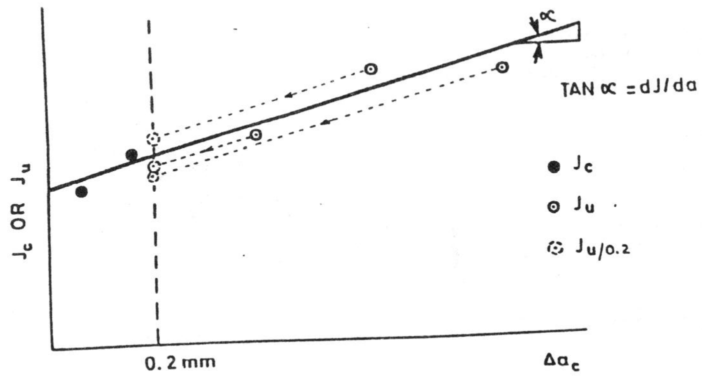

Figure 1 Interpretation of transition regime data

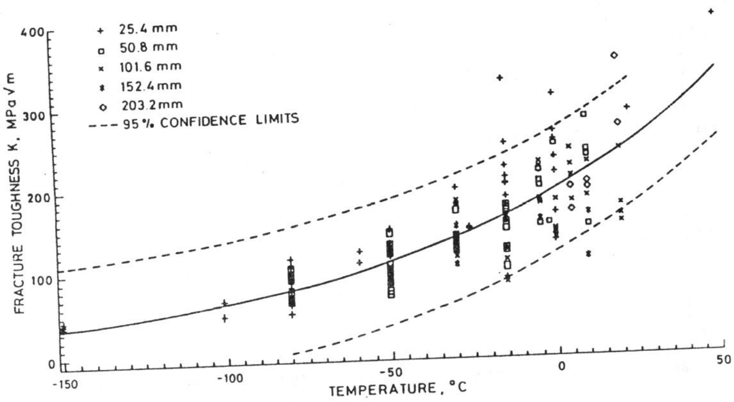

Figure 2 Fracture toughness database from HSSI 5th Series Program

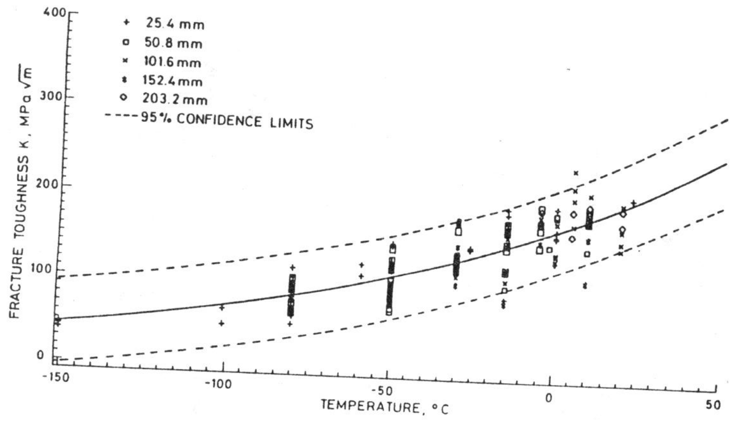

Figure 3 Initiation fracture toughness for the HSSI 5th Series Database

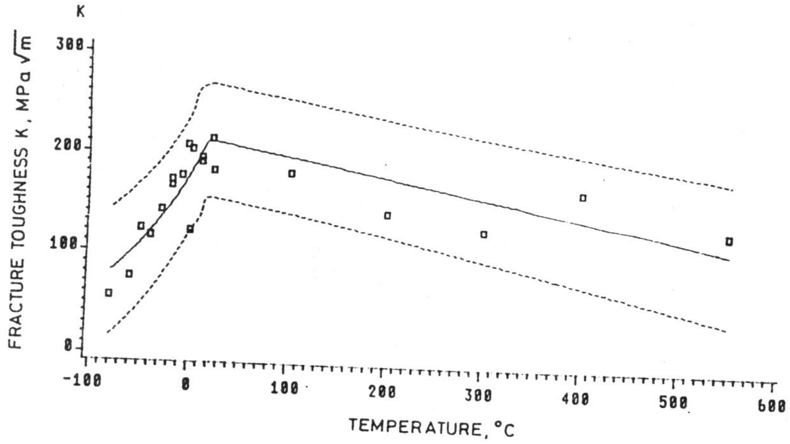

Figure 4 Initiation fracture toughness for an A508 Class 3 forging