A COMPARATIVE NUMERICAL STUDY OF THE DUCTILE TEARING IN WELDED JOINTS USING A GLOBAL AND A LOCAL APPROACH

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This work deals with the ductile tearing of an over-matched welded joint. Considering a CT25 specimen, numerical results in terms of J integral and of the void growth rate parameter R/R_0 have been obtained from a finite element analysis. The global behaviour (J integral) of the trimetallic specimen is governed by the softer material properties but void growth rate results lead to a different conclusion. It indicates that adopting the softer material properties to characterize the fracture behaviour of over-matched welded joints seems to be a conservative approach.

INTRODUCTION

Fracture criteria based upon a global approach are now largely used when dealing with the ductile tearing of metallic alloys. Concerning the welded joints, their micro and macro- heterogeneity lead the searcher to develop more appropriate tools in order to describe the failure behaviour of such components. More precisely, the local approach constitute an alternative and/or a complementary axis of investigation.
In this work, numerical results on a CT 25 specimen issued from two different analysis are compared :
- The potential energy release rate for a crack, J, which can be calculated from the line integral due to Rice (1) :

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$$J = \int_{\Gamma} [W(\varepsilon).dx_2 - \vec{t}.\frac{d\vec{u}}{dx_1}.ds] \qquad (1)$$

- The void growth model developed by Rice and Tracey (2) and expressed as follows :

$$d\left(Ln\frac{R}{R_0}\right) = 0.283 \exp\left[1.5\frac{\sigma_m}{\sigma_{eq}}\right] d\varepsilon_{eq} \qquad (2)$$

Three different configurations have been studied (fig. 1) :

- monometallic (Base Metal BM)
- bimetallic (BM + Weld Metal WM)
- trimetallic (BM + WM + Heat Affected Zone HAZ)

NUMERICAL ANALYSIS

The weld metal and the base metal are respectively a 316L and a Z3 CN 20-09 M stainless steels.The materials behaviour is described using a Ramberg-Osgood power-law of the following form :

$$\sigma = \sigma_e + k\varepsilon_p^n \qquad (3)$$

for each material, the values of σ_e, k and n , are given in table 1.

	BM	HAZ	WM
k (MPa)	1066.9	324.58	324.58
n	0.826	0.206	0.206
σ_e (MPa)	133	220	320

TABLE 1 : the values of σ_e, n et k

Numerical calculations are performed using the SYSTUS finite element program. Large strains, plane strain situation and isotropic hardening with a Von Mises rule have been assumed in the calculations.The finite elements modelling incorporates the eight-noded isoparametric element (six nodes for triangles). The crack is situated in the HAZ, about 1 mm from the melting line (the width of the HAZ is taken equal to 3 mm), while it was assigned at the interface for the bimetallic specimen.

RESULTS AND DISCUSSIONS

For all the configurations, the evolution of the load per unit thickness as a function of the assigned displacement is shown in fig.2. In the case of the base metal specimen, for which experimental results are available a good agreement is pointed out between experimental and numerical data, indicating that the hypothesis of computation are reasonnable. When comparing the bimetallic and trimetallic configurations, a similar behavior is observed. For example, for a given displacement (d = 2 mm), the relative difference between the corresponding loads does not exceed 5 %.

The J integral is computed along different paths sufficiently far from the disturbances induced by the stress concentration at the crack tip. These values are compared, in the case of the monometallic specimen, to experimental data of the energy parameter J determined via the ASTM procedure (3). A good agreement is obtained as shown in fig. 3, where J is plotted versus the loading points displacement. The bimetallic and trimetallic configurations lead to a quite similar evolution of the J-integral, indicating that this parameter is not really affected by the mis-matched strengths of the materials. The global behavior of the bimetallic and trimetallic configurations seems to be governed by the base metal because of its lowest yield stress (5-6).

Figure 4 shows the evolution of the void growth parameter R/R_0 as function of the above mentioned displacement. Note that R/R_0 is computed in the first element immediately ahead of the crack tip. As expected, this parameter is very sensitive to the local stress and strain field distribution, since large differences between the bimetallic and trimetallic specimens are highlighted. This indicate that, in the situation where mismatching is involved, the local approach is more sensitive than the global one. The figure 4 also illustrates the benefical effects of the HAZ when considering the trimetallic specimen. In this case, R/R0 data constitutes a lower limit because it is computed in the HAZ which yield stress is approximatively twice the BM yield stress.Therefore, adopting the softer materials properties to characterize fracture of over-matched welded joints seems to be a conservative approach. Concerning the trimetallic configuration, according to R/R_0 values around the crack will be deviated towards the BM (fig.5

and TABLE 2). This result is important because if crack initiation is governed by a critical value of the void growth parameter, the direction of the crack growth may be described using such a kind of model.

SYMBOLS USED

R : radius of the void
R_0 : initial radius of the void
σ_m : hydrostatic stress
σ_{eq} : equivalent Von-Mises stress
d ε_{eq} : increment of plastic deformation
σ_e : yield strength
n : strain-hardening exponent
k : strength coefficient

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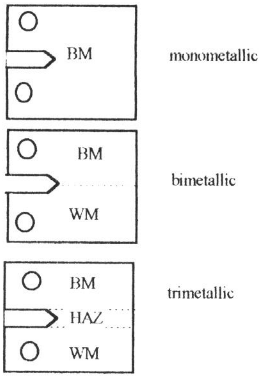

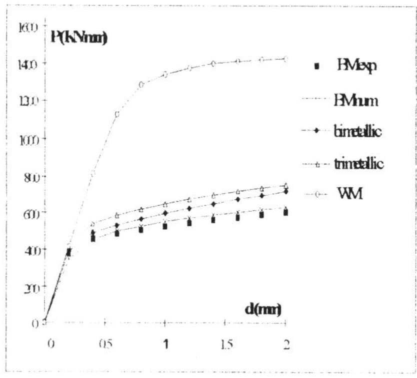

Figure 1 : The different configurations of the CT25 specimen

Figure 2 : load as a function of the assigned displacement.

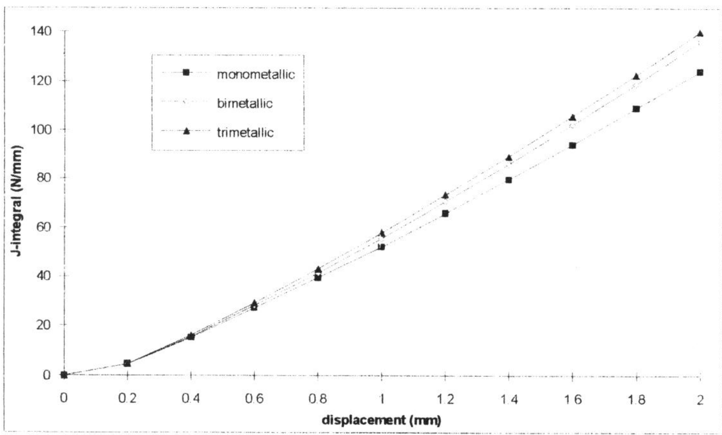

Figure 3 : J integral as function of the displacement

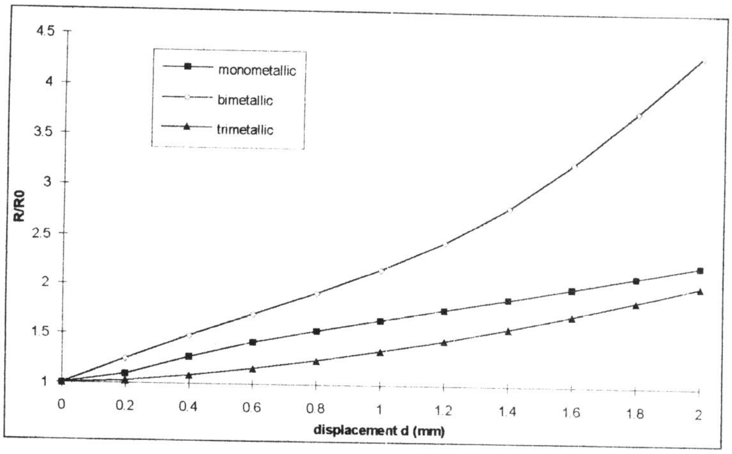

Figure 4 : the void growth parameter vs displacement

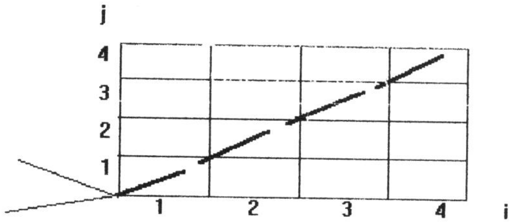

Figure 5: direction of crack propagation (schematic)

j \ i	1	2	3	4
4	1.28	1.22	1.17	1.09
3	1.36	1.30	1.17	1.07
2	1.61	1.39	1.15	1.04
1	2.02	1.33	1.01	1.03

TABLE 2 : R/R0 values around the crack tip