A COMPARATIVE STUDY OF THE RICE&TRACEY AND ROUSSELIER MODELS IN THE ANALYSIS OF THE DUCTILE TEARING

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In this work, a Finite Element (F.E.) analysis of the ductile tearing has been performed. Two theoretical models developed respectively by Rice&Tracey (R.T.) and Rousselier and based upon the local approach to fracture have been investigated. The effects on J resistance curves of the models parameters as well as of the mesh size in front of the crack tip have been pointed out. The numerical results have been compared to experimental data in terms of J resistance curves for a C-Mn steel under a test temperature of 300°C. The two models have been then used to successfully predict the crack propagation direction in a welded joint.

INTRODUCTION

The ductile tearing is generally described using the global approaches of the elastic-plastic fracture mechanics in which only pre-cracked structures are concerned. For ductile materials, the analysis of the behaviour to fracture is generally performed by means of the J integral. But, unfortunately, because of the loss energy processes (plasticity, damage, ...) which may occur in the whole specimen, J is no longer able to predict either crack initiation or propagation since the dissipate energy really depends on the size and geometry of the specimen as well as on the kind of loading. Therefore, local methods have been introduced to analyse the ductile failure because they try to describe the micro-mechanical processes leading to fracture in the vicinity of the crack tip. In such models, since the local parameters governing the failure behaviour are generally related to the stress and strain fields at the crack tip, a F.E. analysis is then required.

In this work, the R.T. void growth model and the Rousselier continuum damage model have been used to describe the ductile tearing of a C-Mn steel. The influence of the models parameters including the effects of the mesh size in front of the crack tip has been

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investigated. The numerical results have been compared to experimental J resistance curves for two components of a welded joint : a base metal (BM) and a weld metal (WM).

MATERIALS

The base metal is a C-Mn steel (A48) and the weld metal is a ferrite-perlite steel . The mechanical properties and the Ramberg-Osgood power law parameters $\left(\sigma = \sigma_y + k\varepsilon_p{}^n\right)$, which have been measured from tensile tests under a temperature of 300°C, are summarised in table 1.

TABLE 1 – Mechanical properties at 300°C.

Material	Yield stress (MPa)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at fracture (%)	Reduction of area (%)	k (MPa)	n
BM	205	433	183	20	54	630	0.26
WM	330	542	197	21	53	600	0.28

NUMERICAL ANALYSIS

The numerical study is performed on a CT25 precracked specimen (a/W=0.5) using the finite element program SYSTUS. Large strains, plane strain situation and isotropic hardening with a Von Mises (V.M.) rule have been assumed. The meshing consists of eight nodes quadratic elements. Close to the crack tip, it is refined using square elements. As the size of these elements is an influential parameter on the local stress and strain fields, two dimensions have been chosen : 0.1mm and 0.2 mm.

Theoretical models of the local approach

In the R.T. model (1) the growth of a single spherical void in an infinite rigid-perfectly plastic material is given in terms of radius evolution as follows :

$$d\mathrm{Ln}\frac{R}{R_0} = 0.283\exp\left(\frac{3}{2}\frac{\sigma_m}{\sigma_{eq}}\right)d\varepsilon_{eq}^p \qquad (1)$$

The R.T. model is characterised by an unique parameter : the critical cavity growth rate $(R/R_0)_c$. Here, this parameter has been determined using experimental data issued from fracture tests on CT specimen. Indeed, since the F.E. analysis of the same specimen gives the evolution of the void growth rate as a function of the J integral, $(R/R_0)_c$ is taken as the value corresponding to J_{IC}.

The crack extension is then simulated using the nodes release technique combined with the fracture criterion $(R/R_0)_c$.

Rousselier (2) has introduced a porous plastic potential Φ to describe the ductile behaviour of the damaged material :

$$\Phi = \frac{\sigma_{eq}}{\rho} + D\sigma_1 f \exp\left(\frac{\sigma_m}{\rho\sigma_1}\right) - R(p) \qquad (2)$$

The fracture behaviour is here controlled by three parameters identification of which is required : the initial void volume fraction f_0, the metallic matrix stiffness σ_1 and a constant D. f_0 can be estimated from chemical composition through Franklin's formula (3). For manganese sulphide inclusions it is written as :

$$f_0(\%) = 5.4\left(\%S - \frac{0.001}{\%Mn}\right) \qquad (3)$$

The second parameter σ_1 is related to the yield stress σ_y. According to Rousselier it can be taken equal to 2/3 σ_y. In practice, tensile testing on axisymetric notched tension specimens is necessary to calibrate σ_1. The values of σ_1 observed in the literature spread from $0.6\sigma_y$ to $1.2\sigma_y$ while the constant D varies from 1.5 to 2.

In this model the crack propagates by a continuum damage of the material when the opening stress at the 2nd Gauss point of the element in front of the crack tip reaches a maximum value.

RESULTS AND DISCUSSION

Mesh size influence

The cavity growth rate R/R_0 is highly mesh size dependent as clearly shown in figure 1 where it appears that the R/R_0 values computed with l_c=0.1mm are higher than those corresponding to l_c=0.2mm . Nevertheless, the gap decreases when going away from the crack tip. Since a crack initiation and propagation criterion requires the critical R/R_0 to be single valued, Delmotte (4) has proposed to take as the critical $(R/R_0)_c$ the value of this parameter at a distance d_c from the crack tip beyond which the variation of the void growth rate becomes mesh size independent (as typically shown for the W.M in figure 1 - d_c=0.3mm and $(R/R_0)_{dc}$=1.9). Unfortunately, such a choice can erase either the crack tip singularity effects or the influence of the gradient of this parameter around the crack tip on initiation and propagation.

Concerning Rousselier's model, the influence of l_c on J resistance curves is shown in figure 2. Indeed, decreasing the mesh size leads to an enhancement of the J values. Therefore, the mesh size has to be considered as an independent parameter in the local approach to fracture and its effects must be carefully pointed out to improve the F.E. analysis of the ductile fracture.

Effects of the model parameters on the J_R curves

The influence of $(R/R_0)_c$ on the « J-Δa » curves is illustrated in figure 3 : an increase of $(R/R_0)_c$ causes a rise in the values of J. Notice that the behaviour to fracture is described by the R.T. model well (especially when considering the weld metal) provided the critical value of the void growth rate is accurately identified.

Concerning Rousselier's model, the effects of the parameters σ_1 and D on the resistance curves are quite different. Indeed, the parameter σ_1 seems to govern the J values while D rather modifies the slopes dJ/da.

Ductile tearing of a welded joint

The ductile tearing of a welded joint has been simulated using a CT specimen composed of the base metal, the weld metal and the heat affected zone. The initial crack is situated in the HAZ at 1mm from the melting line, the width of HAZ being equal to 3mm (figure 5). The aim of this simulation is to predict the crack direction in an over-matched welded joint ($\sigma_{yBM}<\sigma_{yWM}$).

The use of the nodes release technique coupled with the fracture criterion $(R/R_0)_c$ is not possible because such a technique requires assigning the crack propagation direction previously.

On the other hand, a model based on continuum damage mechanics such as Rousselier's one makes the prediction of the crack propagation possible since the elements are automatically damaged. In our case, the F.E. analysis predicts that the crack will deviate towards the base metal as shown in figure 6. Such a result, which has been experimentally observed too, highlights the preponderant effect of the B.M. mechanical properties in the fracture behaviour of over-matched welded components (5, 6, 7).

SYMBOLS USED

D = material constant

f_0 = initial void volume fraction

f = void volume fraction

k = strength coefficient

n = strain hardening exponent

R_0 = initial void radius

R = actual void radius

R(p) = work hardening law

$d\varepsilon^p_{eq}$ = increment of equivalent plastic deformation

ρ = porosity

σ_{eq} = equivalent Von Mises stress

σ_m = hydrostatic stress

σ_y = yield stress

σ_1 = metallic matrix stiffness

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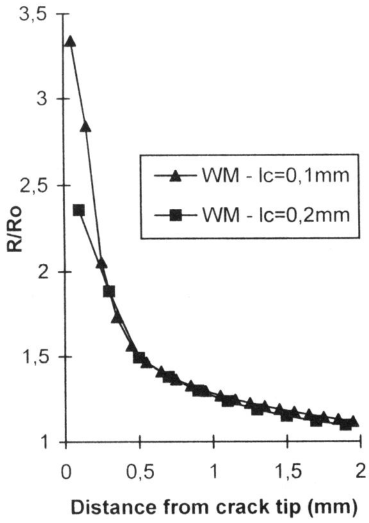

Figure 1 Influence of the mesh size l_c on R/R_0

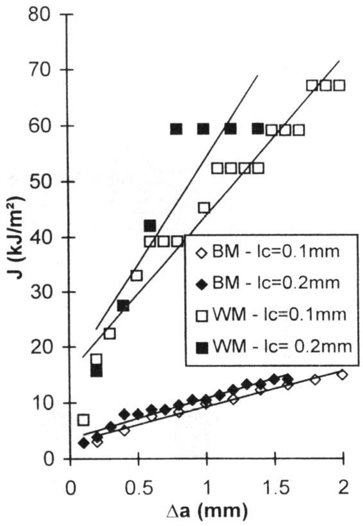

Figure 2 Influence of the mesh size l_c on the J_R curves with Rousselier's model

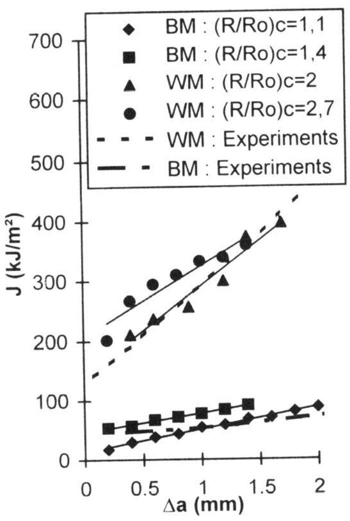

Figure 3 Influence of $(R/R_0)_c$ on the J_R curves

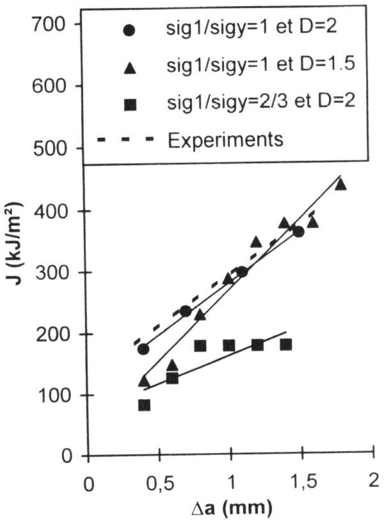

Figure 4 Influence of σ_1 and D on the J_R curves

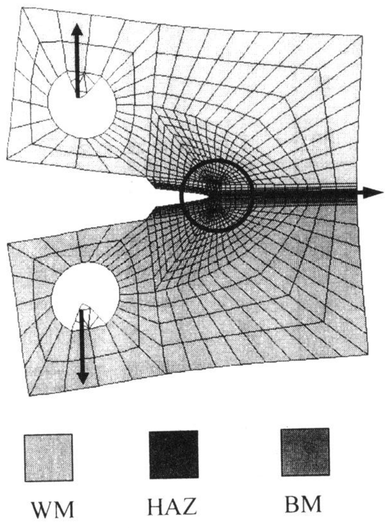

Figure 5 Heterogeneous CT specimen modelising a welded joint (l_c=0.1mm)

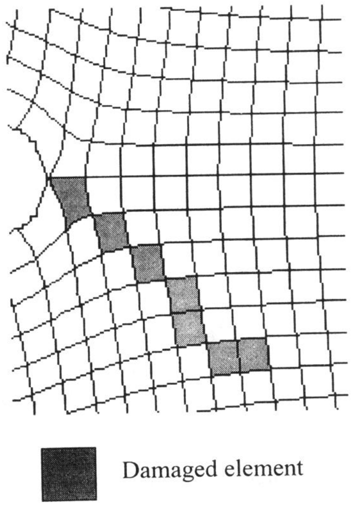

Figure 6 Crack propagation direction in an over-matched structure