ON THE DUCTILE TEARING INITIATION: COMPARISON BETWEEN A COMPLEX STRUCTURE AND CT SPECIMEN

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This article presents a numerical and experimental study on the beginning of ductile tearing in a ferritic material. For that, a first criterion is determined experimentally on two sizes of CT specimen, then discussed and applied as local criterion for the ductile tearing initiation on a cracked branch pipe submitted to an out of plane bending load. Comparison of the estimations of crack initiation and values measured during the structural test are made.

NOMENCLATURE :

a	Crack depth of the semi-elliptical defect.	J	Rice's integral.
		J_i	Critical value for the initiation
Δa	Crack propagation.	$J_{0.2}$	Normalised crack tearing resistance for 0.2 mm crack propagation
2.c	Crack length of the semi-elliptical defect.	SZW	Stretch Zone Width

INTRODUCTION

The evaluation of the integrity of structures is an important subject of nuclear industry, specially for tearing resistance of cracked component submitted to an accidental loading. Two data are then important to evaluate and judge the reliability of the structure : the loading corresponding to the beginning of crack tearing (the crack begins to propagate) and the bearable maximum loading (which creates the collapse of the structure).

- The first point makes the object of an important number of studies and is promising : in the case or a component with a crack, it seems possible to estimate the loading which creates the beginning of tearing with a J criterion depending only on the material. This criterion is determined on small test specimen, then transposed to real structures.

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The second point is more controversial because, to evaluate the bearable maximum loading by the structure, it is necessary to be able to estimate the propagation of the crack : it is this propagation which creates the collapse of the structure with an associated load lower than those estimated without crack propagation. The subject is therefore more difficult because J-Δa curves, currently used for this kind of estimation, are not intrinsic to the material.

In the framework of this study, we are interested only in the first point. Thus, to validate the use of a material characteristic value to characterise the beginning of ductile tearing, and more specially its application to a complex structure, tests have been realized in the CEA/Saclay on cracked Tees. These tests are associated to the material ductile tearing characterization to validate the applicability of the criterion.

MATERIAL CHARACTERIZATION

Tensile Characterization of the material

The material employed for this study is a ferritic steel. It is a 36 mm thickness tube with a 220 mm external diameter. Its chemical composition is given in the table 1.

TABLE 1 - Chemical composition

Component	C	Si	P	Mn	S
%	0.19	0.45	0.016	1.29	0.027

The mean tensile characteristic of the tube, determined with specimen machined in the two directions of the tube (axial and circumferential) are given in the table 2.

TABLE 2 - Tensile characteristic

Young modulus E (MPa)	Yield stress σ_y (MPa)	Ultimate stress σ_u (MPa)
197000	370	550

Definition of a crack tearing criterion.

The current practice to define a critical value of J at the beginning of the tearing consists in determine this value for a normalized crack propagation on the J-Δa curve (in general 0,15 or 0,2 mm). However, this practice leads to portability problems in some configurations.

For this reason, others criteria to define an intrinsic value to the material are proposed. Among the most usable criterion, one can find the practice based on the size of the stretch zone : in an article synthesizing the different criterion and methodologies to characterize the beginning of tearing, Eisele and Roos (5) propose to replace $J_{0.2}$ value by

J_i, defined on the J-Δa curve by the propagation corresponding to the size of the stretch zone (noted SZW). This dimension can be directly measured on the specimen (by observation of the crack front) and thus defined experimentally the critical value of J.

Application of the criterions to the material

Normalized tearing. The first type of test specimen used to characterize the ductile tearing resistance of the material are CT25 specimen (normalized CT specimen with a 25 mm thickness and without lateral notch). The employed methodology is the partial unloading. The J-Δa curve is obtained by this methodology from a unique test. The crack length is estimated from partial unloading allowing to deduce the crack compliance at different load and therefore crack propagation (1)(2).

The second type of tests specimen used are CT12 specimen (normalized CT specimen with a 12 mm thickness and without lateral notch). Because of the small size of the specimen, the employed methodology is now interrupted loading (3)(4). In this methodology, one test gives one point on the J-Δa curve.

The determination of $J_{0.2}$ value for the two sizes of the specimen are shown on fig. 1. As one can see, an importance difference between the two specimens is obtained.

Determination of the Stretch Zone Width : To determine a critical value of J for the beginning of crack tearing as define by Eisele and Roos (5), it is necessary to measure of the Stretch Zone Width. Authors propose to use an observation with an electronic microscope. An example of this type of observation on the CT25 specimen is given on the fig. 2.

The mean value obtained for the Stretch Zone Width is 66 μm and the associated value of J_i determine on the J-Δa curve is J_i = 108 kJ/m² (fig. 1).

APPLICATION OF THE CRITERION TO A CRACKED BRANCH PIPE

To validate this concept of critical value of J at the beginning crack tearing, we have applied it on a cracked Tee, machined in the same material than CT specimen, and submitted to a increasing out of plane loading. This study leans on tests and Finite Element calculations realized at the CEA and described in references (6 to 8).

Test description

The test consists in impose an out of plane bending load to a cracked Tee by embedding the two extremities of the Run pipe and by imposing a displacement at the end of Branch pipe. The crack is located at the foot of the junction and has been obtained from a notch, after a fatigue cyclic loading. Its shape is semi-elliptical with for depth a = 4.2 mm and a width 2.c = 25 mm. During the imposed displacement, the beginning of the crack propagation is detected by a measurement of the Crack Opening Angle (COA) and an Electric Drop Potential measurement on both lips of the crack.

Description of the model of calculation

The model employed for the simulation is a mixed model of Shell and Massive elements. It has been adopted because the plasticity of the material remains confined, during all the test, in the junction. This model has been validated by the analysis of a non crack Tee and submitted to the same loading (6,9). It constitutes an improvement of the first cracked meshes (7,8) with a best account of the crack position. The calculation is made under elastic-plastic and large displacement assumptions.

J calculation

Values of J calculated along the semi-elliptical crack front for the experimental crack initiation loading are presented on the fig. 3. They are compared to the critical value of J_i determined on the CT25 specimen. Maximum values of J along the semi-elliptical crack front is 130 kJ/m². It is in good accordance with the criterion determined on the CT specimen, considering the fact that one does not know exactly the sensitivity of the beginning of crack propagation on the Tee. J_i is therefore transposable from the specimen to the structure. From another point of view, if one uses the maximum value of J along the crack front as criterion to predict the load corresponding to the beginning of the ductile tearing, one obtains a 7% gap conservative value on the load at the beginning of tearing.

The $J_{0.2}$ value determined on the CT25 specimen gives, in this example, a value close to J_i and a good estimation of the detectable crack initiation on the component : if the specimen used to characterize the tearing resistance of the material is large enough, the $J_{0.2}$ value is acceptable as criterion for crack initiation on components. At the opposite, for small specimen, on has to be careful to determine the criterion because an important scale effect may appear and lead to non conservative values.

CONCLUSION

This study has associated tests and calculations on CT specimen and a complex structure to determine a criterion for ductile tearing initiation which is transposable from specimen to structures. The critical value of J_i, defined with the Stretch Zone Width, seems to give a criterion which depends only on the material and thus can be used on components. At the opposite, $J_{0.2}$ is a criterion dependent on the size of the specimen used to determine it, and can leads to important over-estimations of the tearing resistance if the specimen is too small.

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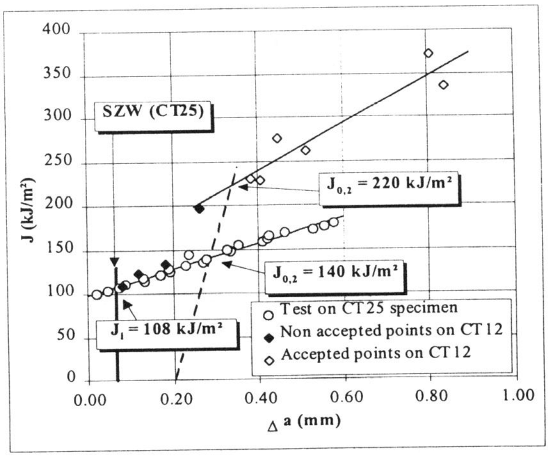

Figure 1 : Determination of caracteristic values of J.

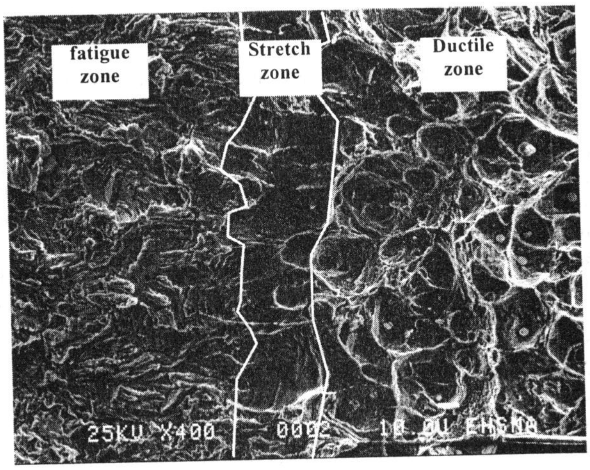

Figure 2 : Microscopic observation of the crack.

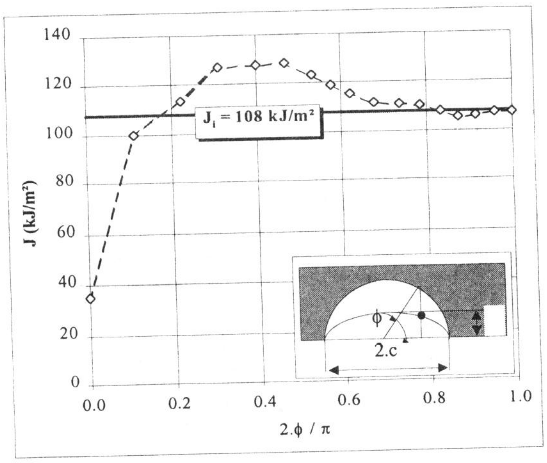

Figure 3 : J calculated for the crack Tee at initiation compared to J_i.