STUDY OF CAST DUPLEX STAINLESS STEEL ELBOW UNDER CLOSURE BENDING

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Electricité de France, in cooperation with CEA and Framatome, is taking a share in a research program to study the fracture behaviour of cast duplex stainless steels. One task of this program consists in testing 2 elbows under closure bending, containing a large semi-elliptical surface crack on one flank. The purpose of this paper is to present results of an elastic 3-D computation performed as to determine the flaw size to be retained for the tests, in order to ensure an in-depth propagation. Comparisons are made with results derived from a stress intensity factor influence coefficients method, and a predictive analysis using the R6 rule failure assessment diagram is presented. Finally, the experimental facility and tests are briefly described.

INTRODUCTION

This work takes a share in a French Research and Development Program on cast austenitic stainless steel components.The main objectives of this program are :

- to study the thermal aging effect on mechanical properties of cast duplex stainless steels,
- to predict the fracture behaviour of components made up with this material by using engineering methods.

The framework of this paper is focused on the preliminary studies that were undertaken to prepare the two elbows tests :

- classification of the loading (primary/secondary) in the elbow submitted to closure bending,
- determination of the flaw size to be considered in the elbow flank, as to ensure an in-depth propagation during the test,
- "prediction" of the crack initiation and propagation during the test, by using the CEGB R6 rule (Rev.3 Option 2) Failure Assessment Diagram .

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TEST DESCRIPTIONS (figure 1 & 2)

	Cast stainless steel elbow	Connecting pipe (Carbon steel)
External radius Re	287 mm	287 mm
Thickness t	42 mm	50 mm
Mean radius Rm	266 mm	266 mm
Bending radius R	900mm	_____
Test temperature	320 °C	_____
Pipe length	_____	5500 mm

MATERIAL PROPERTIES

This experimental material, out of specificati on, has a high ferrite content (larger than 30%) and was aged 700 hours at 400°C. The true stress - true strain curve is plotted on fig. 3. The main properties are, at 320°C :

$E = 176500$ MPa $\qquad \sigma_{TS} = 679$ MPa

$\sigma_y = 276$ MPa $\qquad J_{IC} = 40$ kJ/m^2 (postulated)

DETERMINATION OF STRESS INTENSITY FACTORS ALONG THE CRACK TIP

First of all, we used the results provided from Raju and Newmann (1), and Heliot and al. (2), obtained for an internal surface crack in a cylindrical vessel. We can directly transfer these results from a pipe to an elbow by using the factor C_2 given in the RCCM code (3) to take into account the ovalization effects : $C_2 = 1{,}92\ (Rm / R^*t)^{2/3} = 2{,}963$.

The stress profile in the thickness of the elbow was determined by an elastic FE computation of the uncracked component submitted to the same loading. It was shown that the moment induced a bending stress σ_b in the thickness, and a compressive membrane stress σ_m of about 15% of σ_b.

Different geometries of defect have been investigated in order to evaluate the K_I values obtained along the crack, at the bottom K_{Ia} and at the edges K_{Ic} (figure 5). These results are collected in Table 1, where K_{Ia^*} and K_{Ic^*} are equal to :

$$K_{Ia^*} = K_{Ia}(\text{bottom}) / \sigma_b\sqrt{\pi a} \quad \text{and} \quad K_{Ic^*} = K_{Ic}(\text{edges}) / \sigma_b\sqrt{\pi a}$$

TABLE 1 - K_{Ia^*} and K_{Ic^*} evolutions for different flaw geometries

a/t	0,25		0,4		0,5		0,6	
a/c	K_{Ia^*}	K_{Ic^*}	K_{Ia^*}	K_{Ic^*}	K_{Ia^*}	K_{Ic^*}	K_{Ia^*}	K_{Ic^*}
0,1	0,673	0,354	0,602	0,383	0,528	0,396	0,451	0,421
0,25	0,612	0,505	0,493	0,528	0,399	0,534	0,301	0,520
0,333	0,568	0,532	0,437	0,546	0,338	0,547	0,233	0,548
0,5	0,495	0,560	0,356	0,560	0,256	0,555	0,149	0,561

From these results, it is clear that we should consider a shallow crack, with a large exentricity c/a value, in order to obtain a crack initiation at the bottom of the flaw ($K_{Ia^*} > K_{Ic^*}$), and then a 3 to 5 mm in-depth propagation before large longitudinal tearing of the material occured. Consequently, a long quarter thickness crack, corresponding to a 0,1 a/c value, was retained : a = 10,5 mm and c = 105 mm.

3-D ELASTIC FINITE ELEMENT ANALYSIS

We particularly payed attention to the mesh refinement in the crack tip area. We used solid parabolic elements to describe the whole structure (elbow + connecting pipes) :

- 2040 20-nodes brick elements
- 288 15-nodes wedge elements
- 12 10-nodes tetraedron elements

which are connecting 11068 nodes (figure 4). The element size at the crack tip is about 0,3 mm .

Computation was done with CASTEM finite element code (4). It took about 1000 seconds Cpu to be performed (mesh + resolution) on a YMP-464 computer.

J values were calculated using the Virtual Crack Extension (VCE) method implemented in CASTEM post processing, at both middle and corner nodes.

COMPUTATION / EXPERIMENT COMPARISONS

K_I value profiles obtained by both FE analysis and influence factors method (IFM) are plotted on figure 5. We found out that an analysis using Heliot results(2) overestimates the K_{Ia^*}/K_{Ic^*} ratio of about 20%. The discrepancy that can be noticed when comparing K_I value derived from IFM and FE analysis is about 20% too .

R6 RULE ANALYSIS

The failure assessment diagram was derived from the option 2 , using the true stress

- true strain curve of the material (5). So, we determined the load values at which crack initiation and later unstable crack propagation occured. We predicted (figure 6)

- Δa initiation corresponds to M = 1625 N.m
- Δc initiation corresponds to M = 2030 N.m
- and instability occured for M = 2770 N.m

We can reasonably think that, with the flaw size considered, a stable in-depth crack growth could be obtained during the tests.

EXPERIMENTAL FACILITY AND TESTS

To achieve the experiments mentionned above, a bending test facility was built at "Les Renardières" EDF research center in 1989. This facilty was sized in order to enable testing of pipes, elbows, or branch connections, even under high energy conditions (figure 7).

During the test, the crack growth measurement will be performed by using an alternative current potential drop method. Then, combining the experimental results (load, displacement of the actuator, CMOD, and crack growth versus time) with an elastic plastic FE analysis would provide a J-Resistance curve related to the fracture behaviour of this large-scaled elbow. This curve will be compared to the one gathered from CT specimen tests. A geometry effect on J-R curve would eventually be pointed out.

ACKNOWLEDGEMENTS

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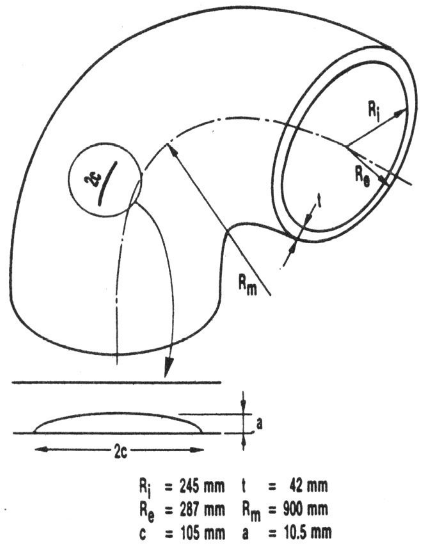

FIGURE 1 - EXTERNAL SURFACE CRACK IN AN ELBOW

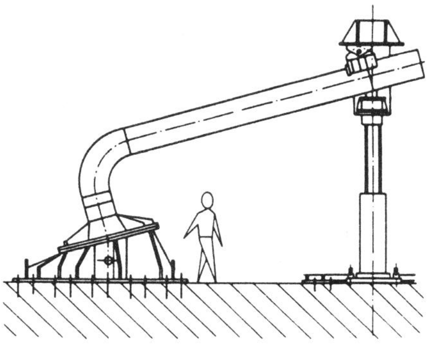

FIGURE 2 - TEST OF AN ELBOW UNDER CLOSURE BENDING

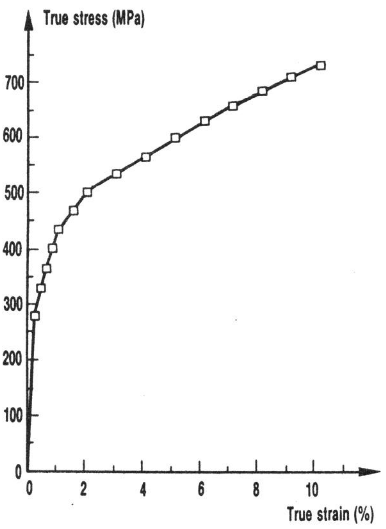

FIGURE 3 - TRUE STRESS - TRUE STRAIN CURVE AT 320°C

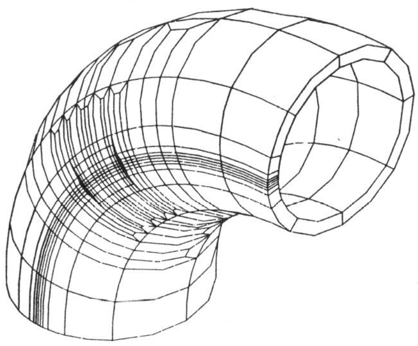

FIGURE 4 - VIEW OF THE MESHED ELBOW

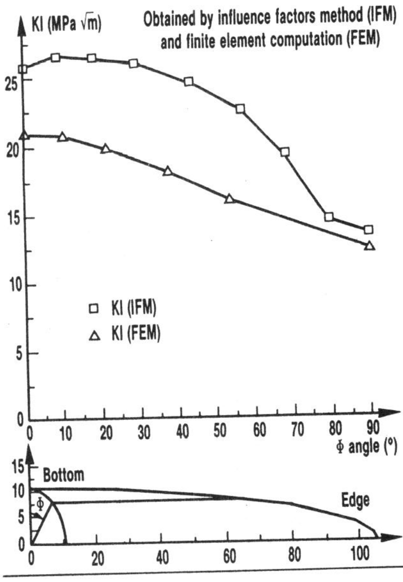

FIGURE 5 - KI PROFILES ALONG THE CRACK TIP

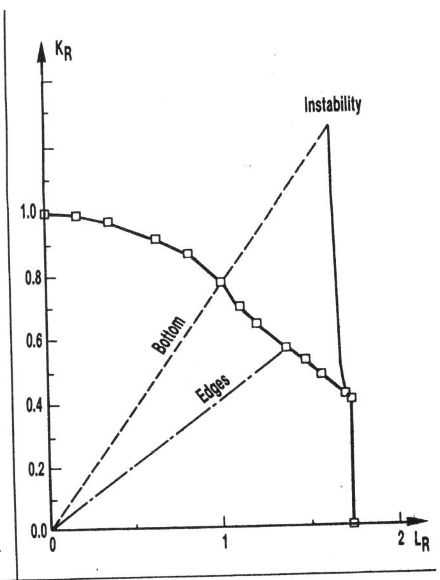

FIGURE 6 - R6 - FAILURE ASSESSMENT DIAGRAM ANALYSIS

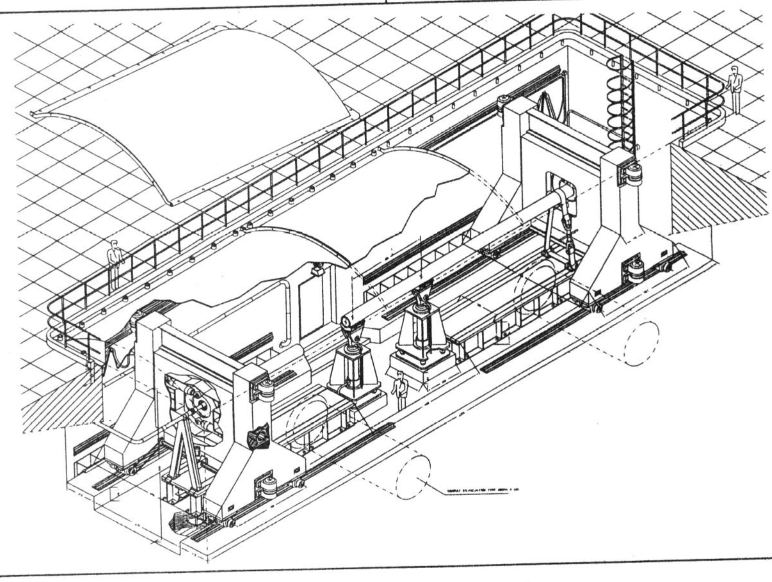

FIGURE 7 - EXPERIMENTAL FACILITY