FATIGUE CRACK GROWTH IN A PRESSURIZED PIPE

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A review of the different problems relative to crack propagation of semi- elliptical surface crack in case of a pipe under pressure is presented. The particular following points are examined:

- crack front evolution during propagation of a semi-elliptical surface crack,
- crack propagation laws for the same kind of crack,
- local value of the stress intensity factor in this case,
- influence of loading mode and SIF value on the parameters C and m of he crack propagation law.

A particular attention was put on a semi-elliptical crack in a pipe submitted to internal pressure.

INTRODUCTION

Propagation of a semi-elliptical crack is oftently observed on the failure surface of engineering structures like pipes, bolts, plates, pressure vessels etc... The safety of a pressure vessel can be asserted using the fracture criterion "leak before break" which needs to know the geometrical evolution of a crack during crack propagation. This evolution is relatively complex. At the beginning, crack growths faster in the direction of thickness than on surface. After this stage, the propagation is more important in the transverse direction (1). Therefore, the prediction of life duration and fracture conditions needs to know the following points :

- What is the evolution of the crack geometry ?
- What is the crack growth governing law ?
- Is this governing law a function of the stress intensity factor and what is the nature of such a SIF (local, average, global) ?
- Are the coefficients of the law intrinsic to the materials ?

This paper will try to answer these questions.

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CASE OF A PIPE SUBMITTED TO AN INTERNAL PRESSURE

EXPERIMENTAL STUDY. Tests have been performed on a special device built in the laboratory and able to submit a thick pipe to a high pressure (up to 70 MPa). This device is shows in figure (1). The material used for the tests is a 35NCDV12 steel (French standard) with thermal treatment. Its mechanical characteristics are given in table (1).

TABLE 1- Mechanical characterstics of the 35NCDV12 steel.

yield stress	ultimate stress	elongation	toughness	parameters of the crack propagation law	
$Re_{0.2}$ [MPa]	Rm [MPa]	A%	K_{IC} [MPa√m]	C	m
1282	1433	11	103	9.2 10E-9	2.77

LOCAL STRESS INTENSITY FACTOR FOR A PIPE SUBMITTED TO AN INTERNAL PRESSURE

Few works have been done to compute the value of the local stress intensity factor in a pipe submitted to an internal pressure. A listing of authors is given in table (2). Finite elements method has been generally used but also the weight functions and the boundary integral method. The results are presented using the following general relationship :

$$K_I(\phi) = \frac{pR_{int}}{t} \cdot \sqrt{\frac{\pi a}{Q}} \cdot M\left(\frac{a}{t}, \frac{a}{c}, \frac{R_{int}}{t}, \phi\right) \qquad (1)$$

M = geometrical correction factor for a crack in a pressurised pipe
p = internal pressure
Q = shape factor for an elliptical crack
ϕ = excentricity angle of the ellipse
R_{int} = internal radius of the pipe
a and c= semi-axes of the elliptical crack
t = thickness of the pipe wall

Few differences have been found between these results. They are only valid for particular geometrical conditions. No experimental determination of the local stress intensity factor have been made. Our experiments shows that in the case of a pipe submitted to an internal pressure, the evolution of the crack shape is different from the case of pure tension or bending. After a transient stage, the crack shape becomes quasi semi-circular and keeps this geometry during all the crack propagation (1). The evolution of crack aspect ratio a/c versus relative crack depth can reach a horizontal asymptote like for a crack in tension and for a value a/c = 1, which corresponds to a semi-circular crack (figure 2).

There is no available results in the litterature for a internal surface crack in a pipe submitted to internal pressure to compare with the results presented in this paper and for this reason the comparison is made only with a plate in tension (figure 2).

TABLE 2 - Works on pressure tubes for SIF calculations.

authors	date	ref.	method	range of validity			
				a/t	a/c	t/R_{int}	results
Kobayashi & al	1977	(2-3)	FDP	.25 to .8	.34	0.1	graph
Hilliot & Labbens	1979	(4)	EIB	.25 to .8	.34	1.1	graph
McGowan & al	1979	(5)	FEM	.25 to .8	.34	1.1	graph
Newman & Raju	1980	(6-7)	FEM	.2 to .8	.2 to1	.1, .25	equation
Boukharouba & al	1995	(1)	FEM	.46 to .7	.7 to 1.12	.25	graph

(WF) : Weight function, (BIE) : Boundary integral equation and (FEM) : finite elements method.

LOCAL AND AVERAGE FATIGUE CRACK GROWTH FOR A PIPE UNDER INTERNAL PRESSURE

Boukharouba & al (1) have analysed the results of the fatigue crack growth of a semi-eliptical surface crack in a steel pipe. They computed the local stress intensity factor range by a finite elements method or using the Newman & Raju's solution (6-7). They compute also the average stress intensity factor range using the Cruse & Besuner's solution (8). Values of local and average crack growth rate da/dN and dc/dN versus the different stress intensity factor range are plotted in figures (3a and b). For the particular points A and C (the deepest point and the surface point) the local crack growth laws can be writen as follows :

$$\frac{da}{dN} = C_{I,A}\Delta K_I^{m_{I,A}} \quad \text{and} \quad \frac{dc}{dN} = C_{I,C}\Delta K_I^{m_{I,C}} \qquad (2)$$

"a" and "c" are repectively the depth and the half length of the crack. In this case, we assume that the knowledge of the local (and average) value of the stress intensity factor on deepest point A, $\Delta K_{I,A}$ $(\overline{\Delta K_{ave,A}})$ and at the surface point $\Delta K_{I,C}$ on $(\overline{\Delta K_{ave,C}})$ is enough to predict the crack growth rate. In addition we assume that the parameters of the local Paris law are identical on point A and C.

$$C_{I,A} = C_{I,C} \quad \text{and} \quad m_{I,A} = m_{I,C} \qquad (3)$$

The conclusions are different from those obtained on a plate (9). The values of the parameter $C_{j,i}$ and $m_{j,i}$ from the semi-local stress intensity factor range are close to the references values C^* and m^* (see figure 4).

CONCLUSION

The propagation of a semi-elliptical surface crack in a pipe submitted to an internal pressure is always an open problem. This works presents for the first time experimental results in this field. Crack front evolution is generally well predicted by empirical relationships. This evolution is influenced by the loading mode and the fundamental mechanisms an not explained and is probably an example of energy minimisation. Crack front evolution is similar to a surface crack in a plate in tension. After a transient period, its tends to become semi-circular. The role of the local or average stress intensity factor is also not very clear. It has been also pointed out that the parameters C and m of the crack propagation law seems to be non intrinsic to the material but depends on the loading mode, the geometry and the local value of the stress intensity factor.

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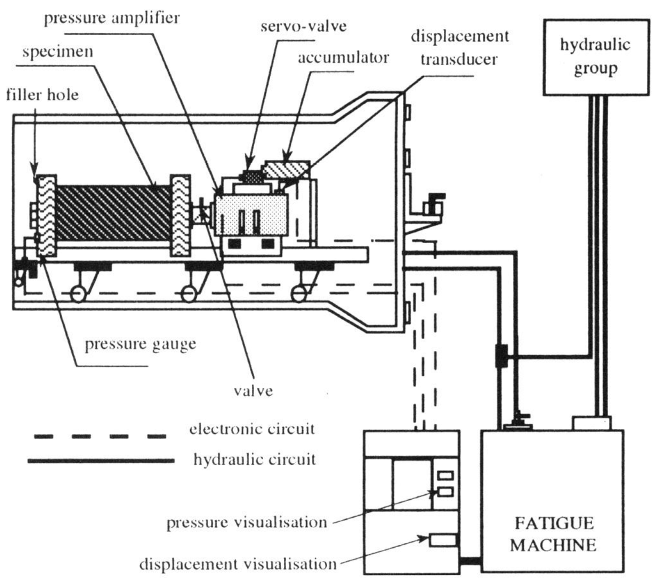

Figure 1 Internal pressure device

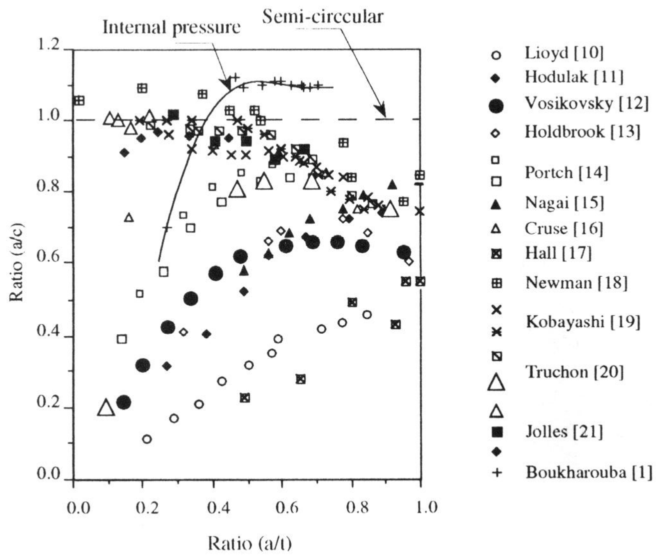

Figure 2 Crack aspect ratio a/c against the relative crack depth a/t

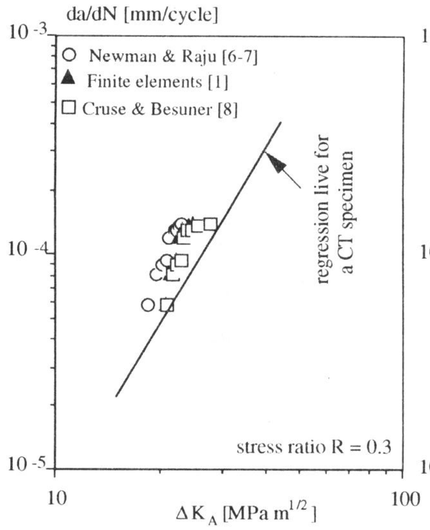

Figure 3a : Crack growth rate at the deepest point da/dN

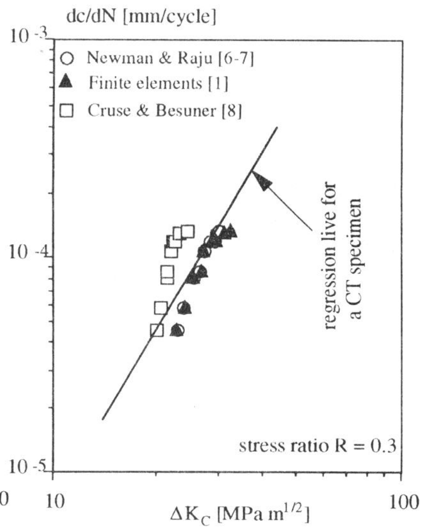

Figure 3b : Crack growth rate at the surface point dc/dN

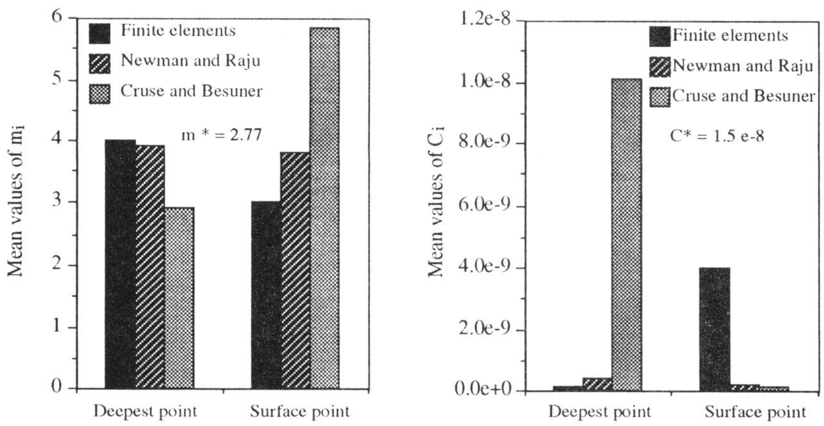

Figure 4 : Experimental determination of the mean values of crack propagation C_i and m_i for Paris's law.