DEFECT IN A CYLINDRICAL SHELL UNDER PRESSURE

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I. Introduction

In the conception phase and the structure dimensionality, it is difficult to foresee the defect treatment that can appear, notably in the new products. It is bound to the fact that the origin of the defect and its propagation depend one several parameters: the material (microcrack, inclusion, and cavity), the conception (geometry, loading), the manufacture (factories defect), and the exploitation (overland).

In presence of a defect, whatever can its origin be, it is necessary to give an answer to preoccupations about the harmfulness by different methods. We all know ruptures examples of structures that unfortunately can have human material damages and in the different industries sectors, notably: automobile, aerospace, railway or nuclear power station. In elasto-plastic, the J integral is the more often used most criteria to quantify the rupture. The aim of this work is to propose simple rules for characterizing the harmfulness of an existing defect in an cylindrical shell under pressure.

II. Different methods to calculate J

* The E.P.R.I method (Electric Power Research Institute)

The EPRI method consists in using a material and a geometry given abacuses permitting to estimate the value of J integral and the maximal load applied one the structures [1, 2].

In this case, the cylindrical shell submitted a load P, the elastic integral J writes itself:

$$J_e = \frac{K_I^2}{E} = f_b^2\left(\frac{\theta}{\pi}\right)\left(\frac{(P)^2}{E(Rb)^2}\right)$$

Where b is a factor which depends on the geometric crack tip, R tube radius, and b tube thickness.

The considered behaviour law is modelised by:

Ramberg-Osgood [1, 3]. $$\frac{\varepsilon}{\varepsilon_e} = \frac{\sigma}{\sigma_e} + \alpha\left(\frac{\sigma}{\sigma_e}\right)^n$$

n hardness coefficient and **α** low behaviour coefficient.

For this type of material, we define the Jp integral by the following expression:

$$J_P = \alpha\varepsilon_e.\sigma_e.c.h\left(\frac{a}{t}, n, \frac{R}{t}\right)\left[\frac{P}{P_0}\right]^{n+1}$$

Where a is the length crack, t thickness of the tube and R his radius mean, C is a characteristic length like the of the ligament, P the applied load and P_0 the characteristic load. h is a function which depends on material geometrie.

h depends on the crack geometry and P_0 on the characteristic loading.

To limit the errors bound of the behaviour modelling law Ramberg-Osgood, Ainsworth [4] proposes a real material behaviour law:

$$\sigma_{ref} = \frac{P}{P_L}.\sigma_e$$

Where P_L is shell limit loading

In this case, the J expression simplified can be written:

$$J = J_e \left(\frac{E\varepsilon_{ref}}{\sigma_{ref}} + \Phi \right)$$

Where ε_{ref} is the reference strain corresponding to the stress references on the real behaviour law and Φ is the plastic zone bottom crack tip in bottom of ace. Ainsworth overestimates diameter by the following expression:

$$\Phi = \tfrac{1}{2} \cdot \frac{\sigma_{ref}^2}{\sigma_{ref}^2 + \sigma_e^2}$$

*** Method supplementary A16 RCC-MR**

The C.E.A engineers have developed a simplified estimation method noted JA16 based on Ainsworth's works. They propose to calculate J plastic by J elastic corrected by a factor which takes in account the plasticity K_{A16} [5, 6, 8 and 9]

$$J_p = K_{A16} * J_e$$

The K_{A16} factor is a corrective coefficient which quantified the plastification level in the crack bottom. It is function of the σ_{ref} stress and the strain referenced ε_{ref} deducted by the stress equivalent in the section

$$K_{A16} = K_{1A16} * K_{2A16}$$

The coefficient which corrects the stress can be written:

$$K_{1A16} = \left(\frac{\sigma_{nor}}{\sigma_n} \right)^2$$

The nominal stress σ_{no} and the real stress nominal σ_{nor} are determined by the material real behaviour law.

The coefficient which takes in account the real strain of the structure is:

$$K_{2A16} = \Psi_{A16} + \frac{E\varepsilon_{ref}}{\sigma_{ref}}$$

Ψ_{A16} is the correction plastic zone:

$$\Psi_{A16} = \frac{1}{2} \frac{\sigma_{ref}^2}{\sigma_{ref}^2 + \sigma_e}$$

The Von Mises' stress in the case of an axisymetric loading is written:

$$\sigma_{eq}=\sqrt{\left(\sigma_{1m}^2+\sigma_{2m}^2-\sigma_{1m}\sigma_{2m}\right)+\frac{2}{2\sqrt{3}}\left|\sigma_{1m}\sigma_{1b}+\sigma_{2m}\sigma_{2b}-\frac{\sigma_{1m}\sigma_{2b}+\sigma_{2m}\sigma_{1b}}{2}\right|+\left(\tfrac{2}{3}\right)^2\left(\sigma_{1b}^2+\sigma_{2b}^2-\sigma_{1b}\sigma_{2b}\right)}$$

σ_{1m}: membrane axial stress,

σ_{1b} : flexion axial stress

σ_{2m} : membrane circumferential stress and σ_{2b} and circumferential flexion stress.

*** R6 method**

The R6 rule proposes a formulation of the plastic correction different of the one definite by the A16 method [7, 8]

$$J_{R6}=\frac{J_e}{(K_r-\rho)^2} \qquad \text{with} \qquad K_r=\left(\Psi_{R6}+\frac{\varepsilon_{ref}E}{L_r\sigma_e}\right)$$

The coefficient ρ depends of the Lr parameter and the primary stress factors intensity K_I^p and the secondary K_I^f respectively the equivalent primary stress in the ligament and the equivalent secondary nominal stress.

$$\Psi_{R6}=\frac{L_r^3\sigma_e}{2E\varepsilon_{ref}} \quad \text{is the correction plastic zone}$$

III. EXPERIMENTAL METHOD

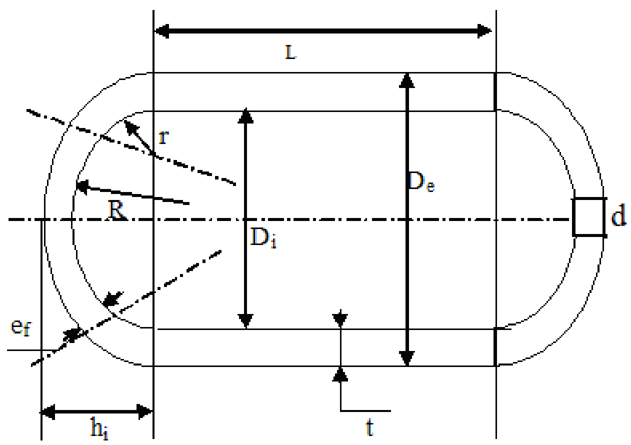
The experimental part, relatively hard to work up, gives the zone deformation near of the crack. In parallel at the time of the tests one follows the evolution of these defects by the acoustic emission method. In this part, we treat the experimental technical mean and the equipments used in the different tests. We will land successively:

- Parameters of the test: the tube geometry, the temperature, the loading, and others parameters according to the test nature.
- Characterization models material: chemical and mechanical composition.
- The different devices used in the tests mechanical and the control means of the evolution crack.

A- specimen characterization

Specimen geometry

The experimental study is realized one specimen constituted of a closed cylinder by two funds torispherical whit big radius GRC fund). The figure (1) represents the parameters that characterize the studied geometry.



t : envelope thickness

Di : interior diameter

De: exterior diameter

D : drilling diameter

r : small edge radius

R : big edge radius

ef : bottom thickness

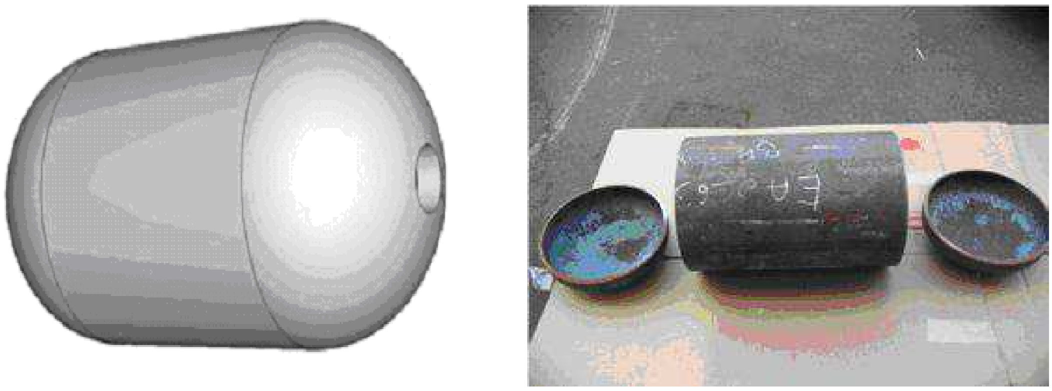


Figure 1: Specimen geometry

1. Cylindrical material characterization

To determine the mechanical characteristic, we have effected the traction test at ambient temperature. The tubes withdrawal has been made in the longitudinal direction. We achieved circular 6 cylindrical right section tubes of diameter 7 mm. The shape and the tubes dimension are represented on the figure (2).

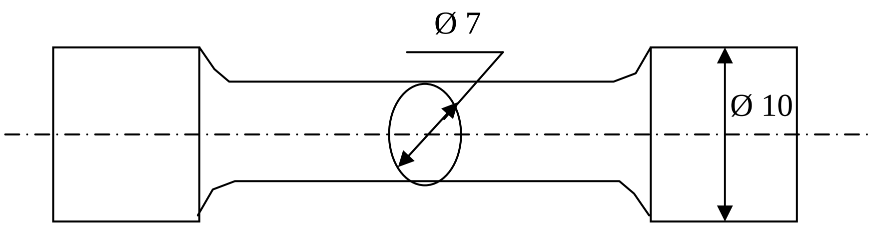


Figure 2: Shape and dimension tubes

The figure (3) represents the experimental conventional stress curve evolution according to the strain. This curve put in evidence the ductile behaviour material

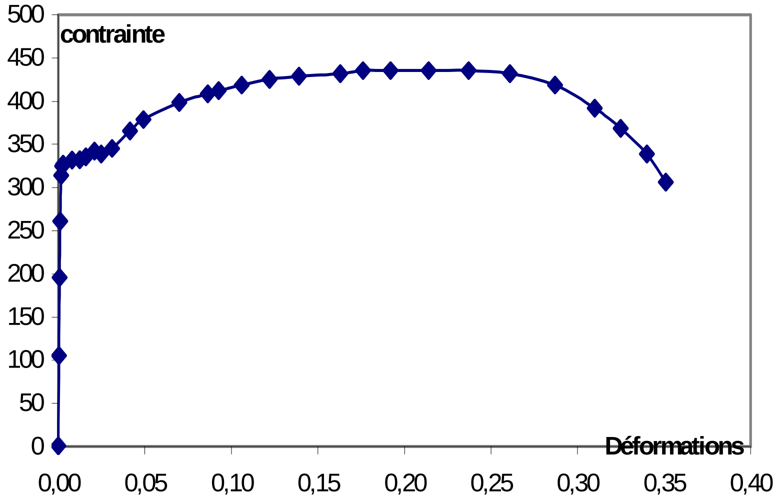


Figure 3: the traction curve

The mechanical characteristic values obtained by the traction tests are summed up on the table (1).

Mechanical characteristic				
Young modulus (MPa)	Poisson's ratio	Yield stress (MPa)	Rupture load (MPa)	Elongation % To%
207000	0,3	360	440	35

Table 1: Mechanical characteristic

The chemical composition of the material has been determined with the help of the electronic microscope, table 2.

%	C	Min.	S	Yew	P	Al
Material	0.135	0.665	0.002	0.195	0.013	0.027
P264GH (max)	0.18	1	0.015	0.4	0.025	0.02

Table 2: Chemical compositions (mass %)

The tests are realized in laboratory with water, the nominal stress calculated is σ_N =147 MPa. The figure 4 gives the different dimensions of the tube.

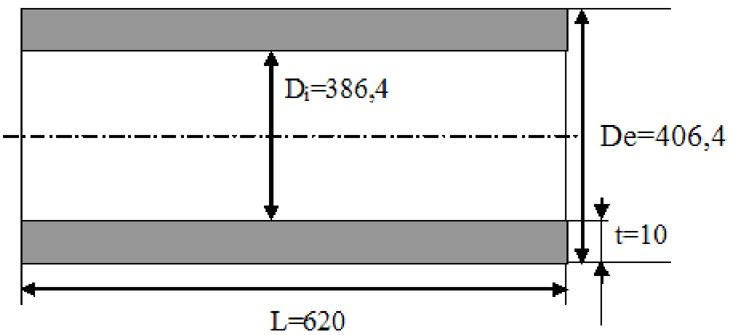


Figure 4: Specimen dimension

Dm: envelope middle diameter

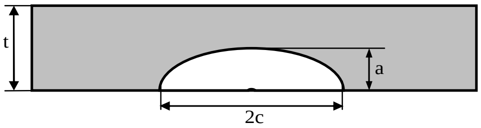
σ_N : envelope nominal stress

Z: welding coefficient. The envelope is appropriated in tubes without welding, one will take z=1.

With the previous dated, one gets has pressed P=74 bars. Pa is the bottom normal presses of crack, Pe correspond at yield stress.

B - Realization of defect

The geometries studied are cylindrical shell including some axisymetrical cracks and elliptical clearing in internal surface or external figs. (3, 4). The semi-elliptic cracks shapes are characterized by two ratio a/t and a/c, with crack depth measured radially and 2.c the crack length, the shell are parameterized by the adimensional ratio (t/R) with t and R is the thickness and the internal radius, figure 5.



The semi-elliptic crack

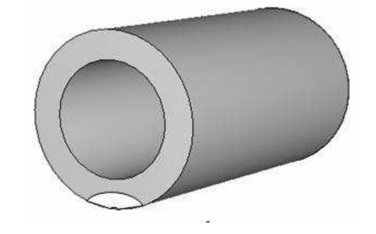
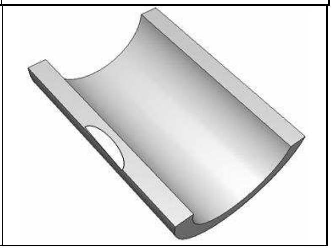
	circumferential semi elliptic crack	axial semi elliptic crack
Externe		

Figure 5: cylindrical geometries

The table III gives the different dimension and orientations of the specimen crack:

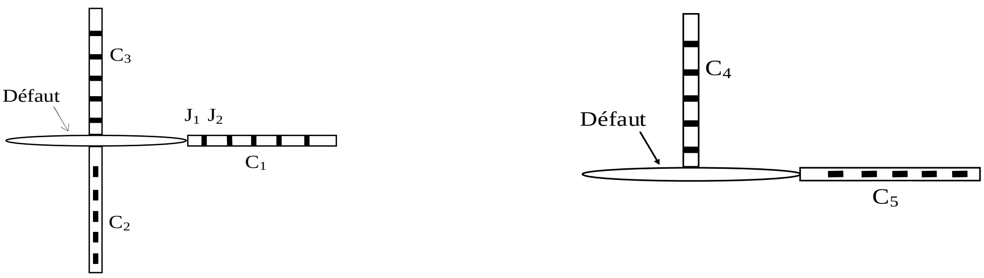
Specimens	defects	Orientations	dimensions
M1	D1	Axial	a = 8 mm, c = 32 mm
	D2	Axial	a = 2 mm, c = 8 mm
M2	D3	Circumferential	a = 8 mm, c = 32 mm
	D4	Circumferential	a = 2 mm, c = 8 mm
M3	D5	Axial	a = 4 mm, c = 16 mm
	D6	Circumferential	a = 4 mm, c = 16 mm

Table 3: Defect dimension

C. SPECIMEN INSTRUMENTATION.

For this study, we aim several objectifies:

- To determine the experimental strain distribution near of the crack (elastic domain), in order to validate our numerical models. The specimens are instrumented by some gauges in the defect zone (figures (6 and 10). The numerical results are a base in this work. In the optimal comparison, a total of 90 gauges was necessary for this study.



Position and orientation gauges (defect D_1) Position and orientation gauges (defect D_2)

Figure 6: Position and orientation gauges

- To follow the crack evolution by an acoustic emission and by strain implantation.

The sensors of acoustic emission are implanted according to the figure 7:

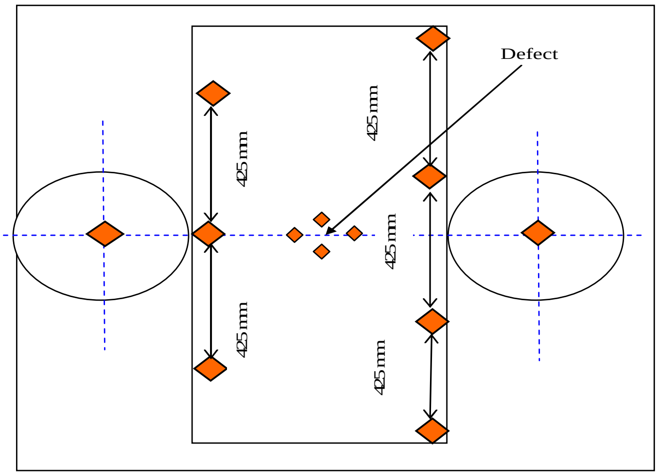


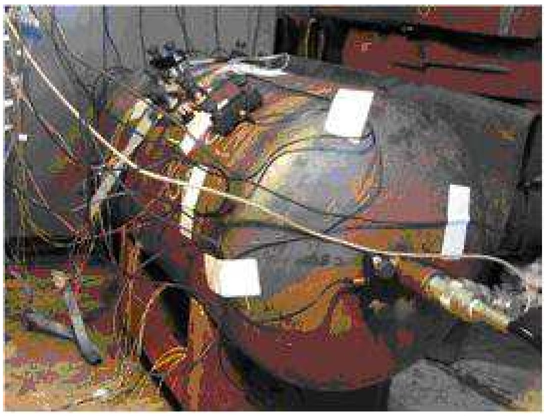
Figure 7: Principal sensors acoustic emission

In every specimen studied, we used 14 sensors (two reasoning to 30 kHz and 12 to 150 kHz), figure 7.

Sensitivities verification.

After the puts of every sensor, its sensitivity is verified with the help of a Hsu-Nielsen source (3 mines crack to 5 cm and 20 cm). For each of the both distances, the measure of all sensor should be consisted ± 3db. Besides, for each sensor, the mean of the three mines ruptures average to 5 cm, should be to the minimum of 80 dB, without chain saturation. A references calibration is done, it will crack comparison basis to verify the sensitivity stability of measure chain detection before, after and possibly test during.

Measure Chain



Specimen gauges and sensors acoustic emission

Figure 8: Acoustic emission

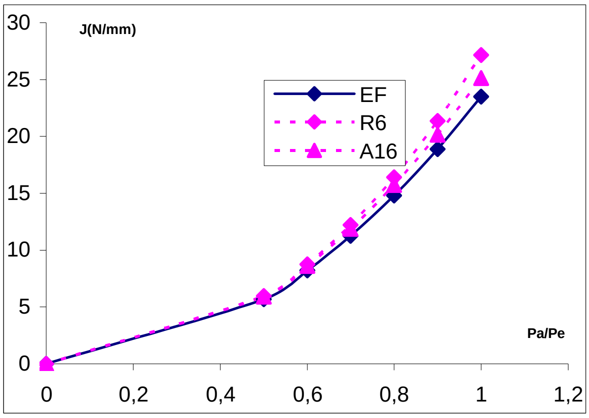
III. RESULTS

The J calculation is directly realized by finite elements then by rules simplified R6 and A16. The results will be given according to the adimensional parameter Pa / Pe.

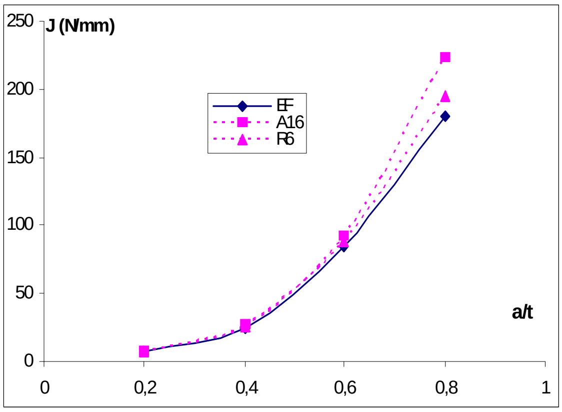
Noting that this constant loading on the crack bottom translates the constant global loading case internal pressure, the most fluently met in practice in the industrial.

We notice that for the weak loads (Pa / Pe = 0,6), the methods simplified R6 and A16 estimate correctly the J integral. It is due to the weak plastification in crack bottom. More the load increases bigger is gap between the different methods. In any case, J increases naturally with the applied load, figure 9.

We notice that in any case, the simplified methods overestimate the J. integral and are therefore conservative in term of security.

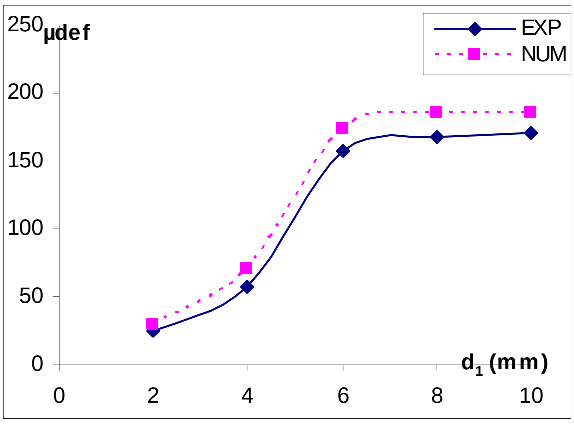


J evolution according the load (a/t=0.8, a/c=1/4 et t/Ri=1/10)

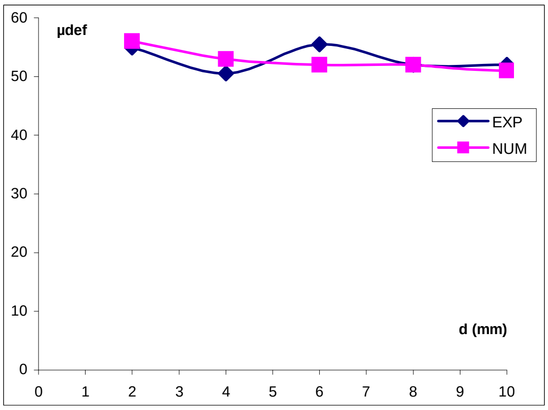


J evolution according the load de a/t (a/c=1/8, Pa/Pe=0.8 et t/Ri=1/10)

Figure 9: J evolution according the load



Deformations circumferential according of distance (P=2,5 MPa, M1, C4)



Deformations circumferential according of distance (P=2,5 MPa, M1, C5)

Figure 10: Deformations circumferential according of distance

IV. CONCLUSION

We studied the J integral by different methods:

- By finished elements while using the method so-called" G-THETA
- By the simplified rules of R6 or A16

The simplified methods permit to approximer the J integral contour from its value gotten in the elastic domain, with an analytic correction and as making intervene load limits. These semi analytic methods have been validated by comparison with the numerical solutions gotten by finite elements in the elasto-plastic domain, and that are near of the experimental results. The results gotten by the numeric and semi-analytic methods are very near the some of the other, and we especially notice that the J values gotten from the R6 and A16 methods are always superior to those gotten by finite element. Even if the gaps are more important when the loading is very bigger, the J evaluation simplified methods always present a conservatif character:

An experimental study is realized on shell cylindrical provided with circumferential and longitudinal defect.

The strain gauges instrumentation show an adequacy between the experimental and theoretical values.

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