DETERMINATION OF FRACTURE LOAD BY ACOUSTIC EMISSION

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Abstract: A comparison of fracture load given by conventional definition and acoustic emission is made for three cases :

- Fracture load at maximum load,
- Fracture load at "pop-in",
- Critical load defined by 5% offset procedure.

Comparison has been made for three materials, Steel APX 52, Honeycomb core composite and 7000 T 73 aluminium alloy.In each case, good agreement is found between acoustic emission and conventional fracture load. Acoustic emission is a power full method to detect the critical event particularly when large plastic deformation occurs before ductile tearing.

Key words : Acoustic emission, fracture load, composite, steel, aluminium alloy.

I) INTRODUCTION

The acoustic emission phenomenon is known from long time in hearing form (the tin cry of the blacksmith) and has been first object of research by Kaiser in 1950 in the field of ultrasonic frequency. First applications have been done for inspection of Polaris Rocket in in USA (1964). In France, acoustic emission is used since 1978 for sealing inspection of primary circuit in nuclear pressure vessels.

Acoustic emissions (AEs) are the stress waves produced by the sudden internal stress redistribution of the materials caused by the changes in the internal structure. Possible causes of the internal-structure changes are crack initiation and growth, crack opening and closure, dislocation movement, twinning, and phase transformation in monolithic materials and fiber breakage and fiber-matrix debonding in composites. Most of the sources of AEs are damage-related; thus, the detection and monitoring of these emissions are commonly used to predict material failure.

Besides the applications of AE in research endeavours, AE has been widely used in industries, including for the detection of faults or leakage in pressure vessels, tanks, and piping systems. AE is also used to monitor the welding and corrosion progress.

The difference between the AE technique and other non-destructive evaluation (NDE) methods is that AE detects the activities inside the materials, while other NDE methods attempt to examine the internal structures of the materials. Furthermore, AE only needs the input of one or more relatively small sensors on the surface of the structure or specimen being examined so that the structure or specimen can be subjected to the in-service or laboratory operation while the AE system continuously monitors the progressive damage. Other NDE methods, such as ultrasound and x-ray, have to access the whole structure or specimen, and therefore, the structure or specimen often needs to be disassembled and taken to the laboratory to be examined.

The disadvantage of AE is that commercial AE systems can only estimate qualitatively how much damage is in the material and approximately how long the components will last. So, other NDE methods are still needed to do more thorough examinations and provide quantitative results. Moreover, service environments are generally very noisy, and the AE signals are usually very weak. Thus, signal discrimination and noise reduction are very difficult, yet extremely important for successful AE applications

The traditional AE method only captures certain parameters (sometimes called AE features), including AE counts, peak levels, and energies. Then, the AE features are correlated with the defect formation and failures. These AE characteristics are only related to the captured signals and do not account for the source of the signal and wave propagation.

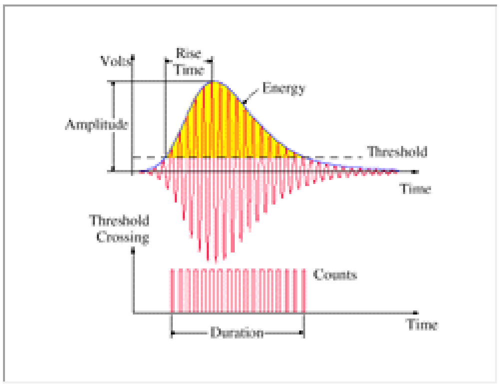


Fig 1. The definitions for acoustic-emission events.

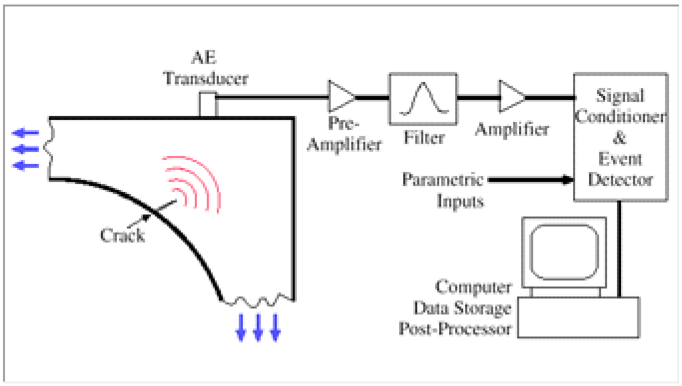


Fig 2. A typical AE system setup.

Figure 1 shows a burst AE signal and the commonly used parameters of AE techniques. When the AE transducer senses a signal over a certain level (i.e., the threshold), an AE event is captured. The amplitude of the event is defined at the peak of the signal. The number of times the signal rises and crosses the threshold is the count of the AE event. The time period between the rising edge of the first count and the falling edge of the last count is the duration of the AE event. The time period between the rising edge of the first count and the peak of the AE event is called the rise time. The area under the envelope of the AE event is the energy.

Figure 2 presents a typical AE system setup. The AE transducers are generally very sensitive piezoelectric sensors. Because the traditional AE technique only uses AE features, the actual waveforms are not critical to this method. The AE sensors (transducers) used are usually resonance sensors, which are only very sensitive to a certain frequency. Since the AE signals are very weak, a preamplifier is connected right after the AE transducer to minimize the noise interference and prevent the signal loss. Sometimes, the transducer and the preamplifier are built as a unit. Then, the signals pass through a filter to remove the noise. The signals are amplified by the main amplifier before being sent to the signal conditioner. After that, the AE features are subtracted and stored in a computer for further analysis. During investigations, other parameters, such as load, deformation, pressure, and temperature, can also be recorded as parametric inputs.

2. CRITICAL LOAD DEFINITIONS

Critical load is defined as the maximum load that a given system can tolerate before failing. However this definition is related to failure which can be local or global [1]. At local level, failure depends of conventional scale of observation. A typical example is given in figure 2 of global and local failure.

In figure 3a, a macroscopic failure with two broken piece is considered and the critical load is defined as the maximum load. In figure 3b at a local level, a stable crack extension initiates from a defect or an inclusion appears during loading. This event is characterises by a small set back on the load displacement curve. In addition, a ”pop-in” can be heard. In this case the load corresponding to the set back is considered as the critical load. In fig 3c, the load displacement curve is smooth and critical load is defined with a conventional 5% offset of the curve which corresponds to a given extension of plasticity characterises by dislocation cells. Trends is to use a definition corresponding to a very small event according to principle “ failure is the beginning of the end of the structure”. AE which detects dislocations movement can be used as a conservative way to define critical load.

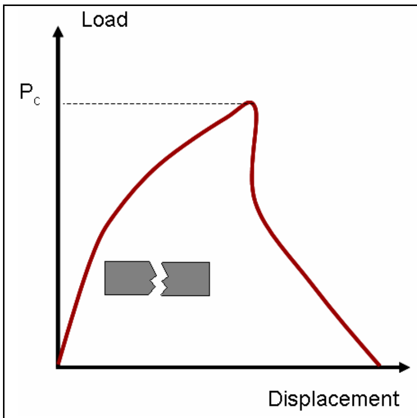


Fig 3a. Critical load defined at maximum load.

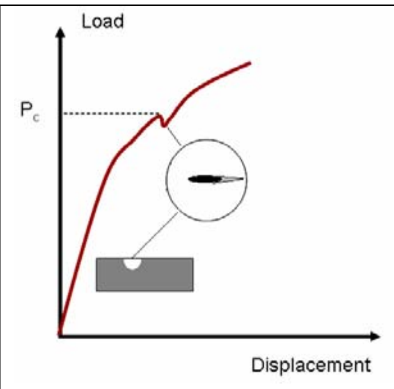


Fig. 3b. Critical load defined at setback.

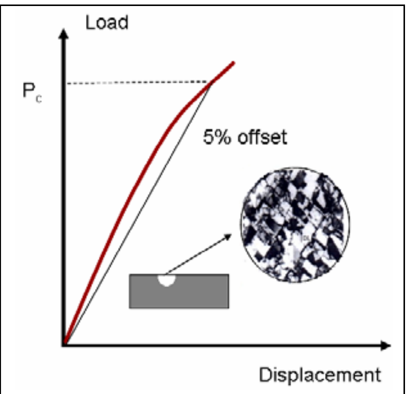


Fig. 3c. Critical load defined at 5% offset.

3. CRITICAL NOTCH STRESS INTENSITY FACTOR AS A MEASURE OF FRACTURE TOUGHNESS

The critical notch stress intensity factor is a local fracture criterion that the fracture process requires a certain fracture process volume. This volume is assumed as cylinder with diameter called effective distance. Determination of this effective distance is based on the bi-logarithmic elastic-plastic stress distribution because the fracture process zone is the highest stressed zone. This zone is characterized by an inflexion point on the stress distribution at the limit of zone II and zone III on Figure 4. Justification of this method has been given in reference **Error! Reference source not found.**.The determination of the effective distance is accomplished using the minimum of the relative stress gradient □ which corresponds to this inflexion point. □□ is given by□□

$$\chi(r) = \frac{1}{\sigma_{yy}(r)} \frac{\partial \sigma_{yy}(r)}{\partial r} \tag{1}$$

where $\chi(r)$ and σ_{yy} are the relative stress gradient and maximum principal stress or crack opening stress, respectively. The effective stress is considered as the average value of the stress distribution inside the fracture process zone. This stress distribution is corrected by a weight function in order to take into account the distance from notch tip of the acting point and the stress gradient at this point.

$$\sigma_{ef} = \frac{1}{X_{ef}} \int_0^{X_{eff}} \sigma_{yy}(r) \times \Phi(r)\, dr \tag{2}$$

where σ_{ef}, X_{ef}, $\sigma_{yy}(r)$ and $\Phi(r)$ are effective stress, effective distance, maximum principal stress and weight function, respectively.

The notch stress intensity factor describes the stress distribution in zone III. By extension the notch stress intensity factor, it can be defined as a function of the effective distance and effective stress **Error! Reference source not found.**:

$$K_\rho = \sigma_{ef}\sqrt{2\pi X_{ef}} \tag{3}$$

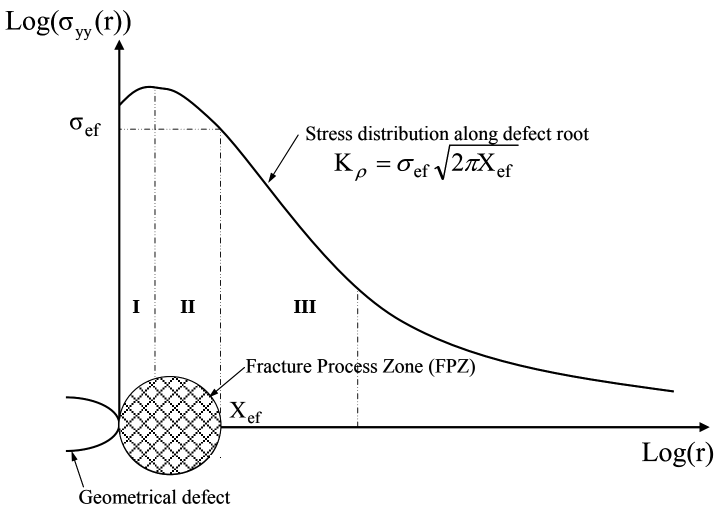


Fig. 4. Schematic elastic-plastic stress distribution along notch ligament and notch stress intensity virtual crack concept.

4. CRITICAL LOAD DEFINED AT "POP-IN"

This example is made with APIX52 steel. The API X52 was the most common gas pipelines material for transmission of oil and gas during 1950-1960. The chemical composition of API X52 is shown in Table 1

Table 1. Chemical composition of API X52 (Weight%).

C	Mn	Si	Cr	Ni	Mo	S	Cu	Ti	Nb	Al
0.22	1.22	0.24	0.16	0.14	0.06	0.036	0.19	0.04	<0.05	0.032

In Table 2, mechanical properties of API X52 are presented. This material exhibits a large elongation and ductile behaviour is expected.

Table 2. Mechanical properties of API X52.

E (GPa)	σ_Y (MPa)	σ_U (MPa)	**A%**	**n**	**K** (MPa)	$K_{\square,c}$ (MPa√m)
203	410	528	32	0.164	876	116.6

where E, σ_Y, σ_U, $A\%$, n, K and K_c^* are the modulus of elasticity, yield stress, ultimate stress, relative elongation, hardening exponent, hardening coefficient and fracture toughness, respectively. The fracture toughness has been obtained with "roman tile" specimens presented in Figure. 5.

This special device and specimen have been developed due to impossibility to get flat specimen from small diameter pipes.

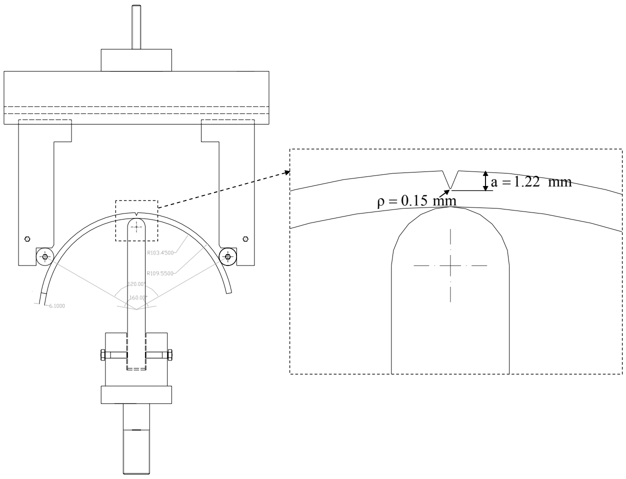


Fig. 5. Experimental test setup for measuring fracture toughness of pipe steel using "roman tile specimen".

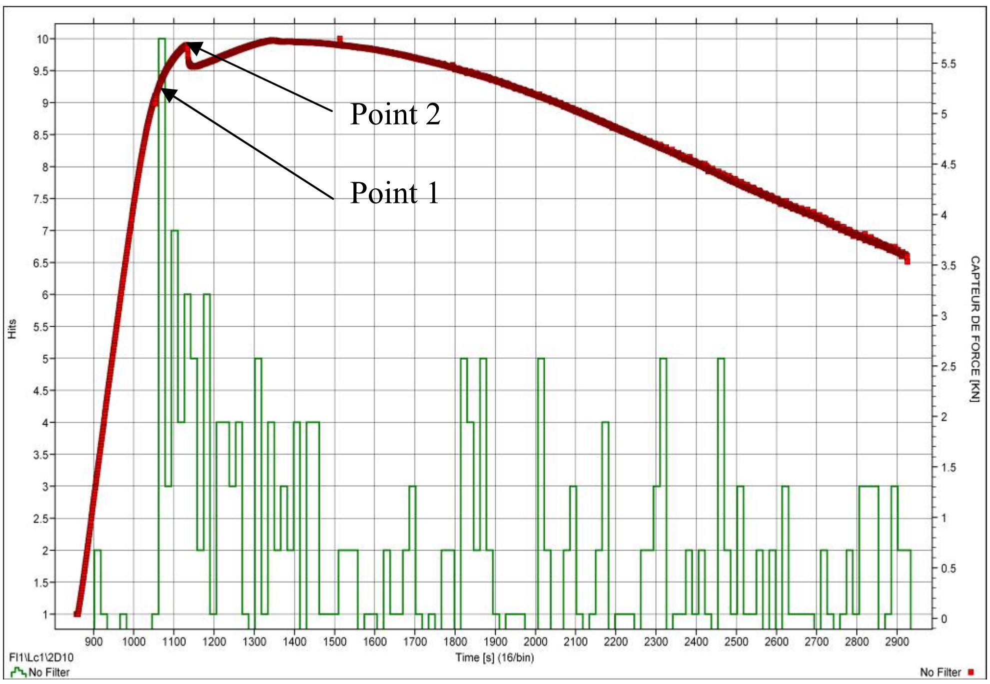


Fig. 6. Load-Hits versus time.

Figure 6 presents typical load –time (or displacement at constant rate) and hits –time curves. Critical load is defined for acoustic emission as the load corresponding to maximum hits (point1) and in conventionally in fracture mechanics as the load corresponding to the set back (point 2) . These two loads are close as we can see on figure 7. These critical load are introduce in FEM computing in order to get the effective stress and effective distance and then to get fracture toughness as the critical notch stress intensity factor. $K_{\rho,c}$. tests have been performed and analyse statistically with Weibull distribution. Mean values and Weibull modulus for the two methods of determining critical load (Acoustic emission and setback) are given in table 3. We can note that by looking at mean value that fracture toughness is relatively low for this steel. Explanation is given by relative high content of sulphur. Two mean values are close but acoustic emission gives a value higher of 15%. Difference in scatter is more pronounced if we compare the Weibull modulus values. Acoustic emission gives considerable low scatter value.

Table 3. Fracture toughness and scatter of API XR2 steel measured on roman tile specimen.

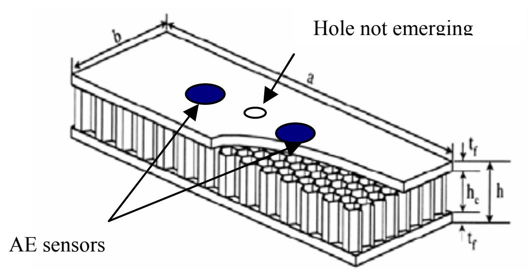
Fracture Toughness	Mean value (MPa√m)	Weibull modulus
Acoustic emission	57,443	74
5% offset	48,29	24

5) CRITICAL LOAD DEFINED AT MAXIMUM LOAD

This example is given from sandwich panels from aluminium core and pure aluminium face sheet. Honeycomb core is an opened cell with a density of 82 kg/m^3 of aluminium core. The cell size is 6.4 and 9.6 mm. The dimensions of these panels are shown in Table 4.

Table 4: Specimen dimensions.

L (mm)	b (mm)	h (mm)	h_c (mm)	t_f (mm)	L_2 (mm)	L_1 (mm)
500	250	10	8,80	0,60	420	210



Panels with defects were tested in four point bending and were monitoring with acoustic emission as shown in Figure 7.The tests were carried out in a servo hydraulic Instron 4302 universal testing machine with 10 kN capacity and 2mm/min.crosshead velocity. 5.

Representative load-displacement of aluminium-aluminium sandwich beams is shown in Figure 8. It was observed that the sandwich structures present a maximum ultimate load and exhibit ductile behaviour. At the beginning of the plasticity domain, there is an intense AE activity like at the catastrophic failure.

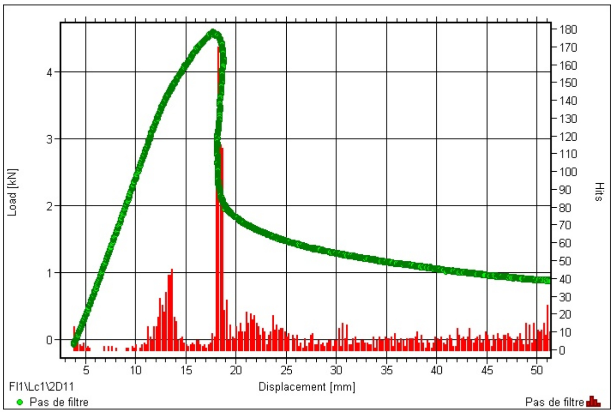


Fig. 8. Load-Deflexion of sandwich panels L direction.

6) CRITICAL LOAD DEFINED BY A 5% OFFSET PROCEDURE

Fracture toughness has been determined on aluminium alloy. Chemical composition of this alloy is given in figure 9. Yield stress of this alloy is Re = 285 MPa and ultimate strength Rm = 346 MPa, Fracture toughness is K_{Ic}= 38 MPa√m . Specimens are TPB specimen with a thickness of 10mm with 5 different notch radius (O.15, 0.3, 0.5 , 0.8 , 1 mm). A typical load and acoustic energy versus time is given in figure 9. No particular event can be detected on this smooth load time diagram. Critical load is given by the 5% offset procedure. For this procedure, we draw a line from origin with a slop which differs from initial slope of 5%. The intercept with load time displacement gives coordinates of critical load and critical time. This critical load is called $P_{5\%}$. The physical meaning of this procedure is that we accept a plastic zone plus stable crack growth extend less than 2% of the ligament size before conventional fracture. In the same time, we registered acoustic emission energy. The first burst of acoustic energy before large and final burst is considered as critical event. Corresponding load is called $P_{AE.}$

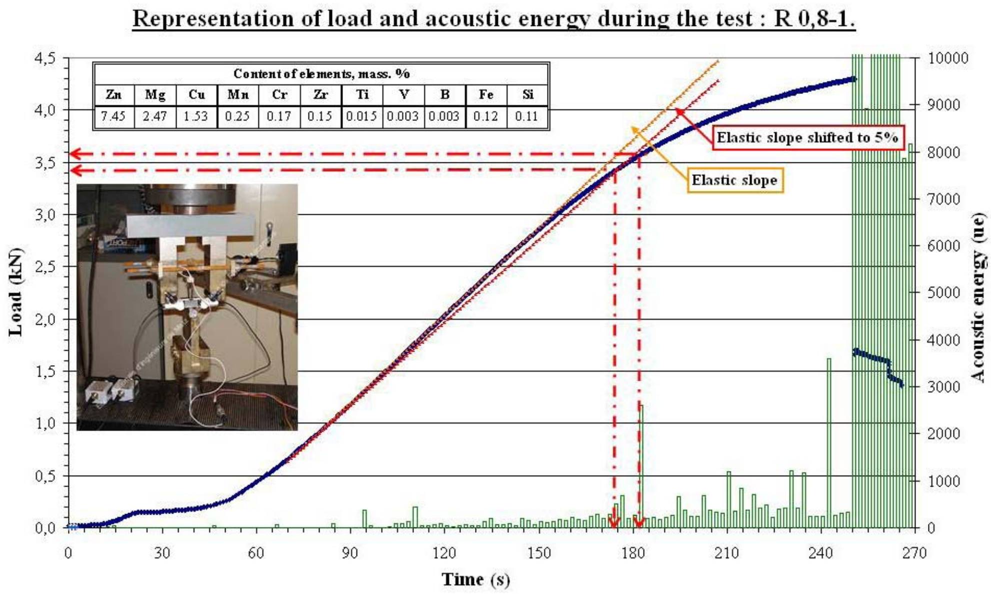


Fig. 9. Example of load and acoustic energy versus time for aluminium alloy specimen.

Error between two methods has been defined as follows:

$$Error * 100 = \frac{P_{AE} - P_{5\%}}{P_{5\%}} \quad (4)$$

Error has been plotted versus notch radius in figure 10 . We can notice than maximum error doesn't exceed 12 % which is acceptable.

7) CONCLUSION

A comparison of fracture load given by conventional definition and acoustic emission is made for three cases. In each case, good agreement is found between acoustic emission and conventional fracture load. For fracture occurring with a large amount of plasticity, acoustic emission is a necessary and possible additional method to detect with accuracy critical load.

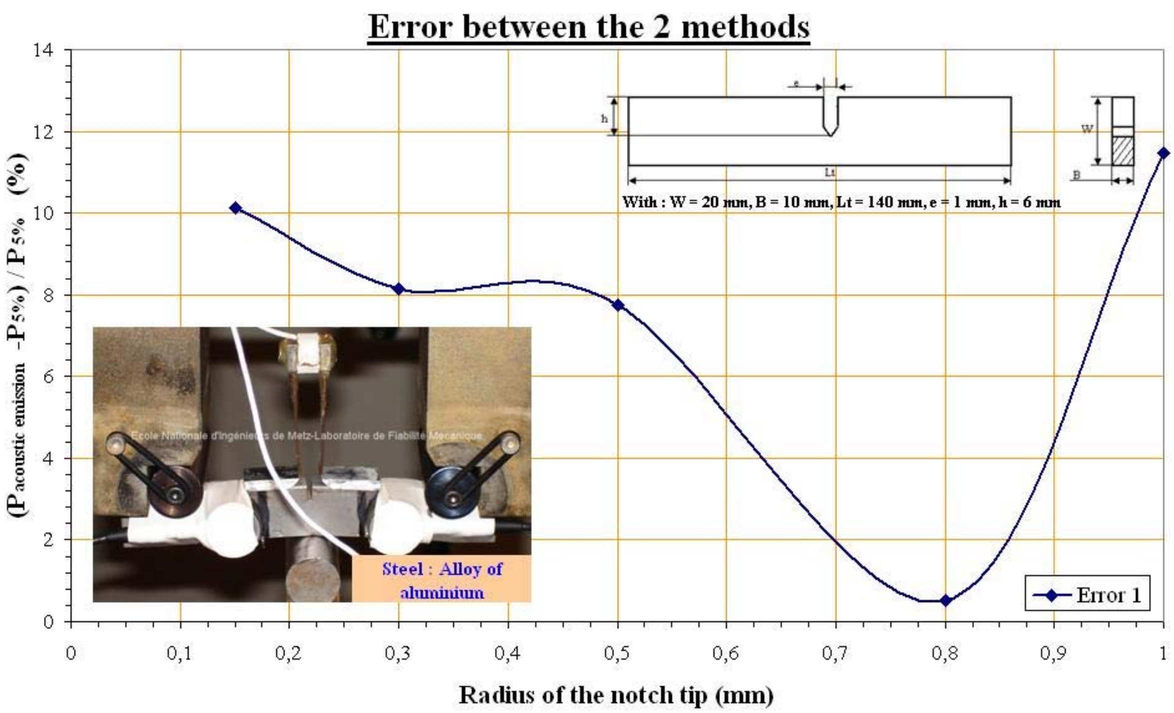


Fig. 10. Error between two methods versus notch radius.

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[2] G Pluvinage Fracture and Fatigue emanating from stress concentrators; Editeur Kluwer, (2003).