ACOUSTIC EMISSION TECHNIQUE AND POTENTIAL DIFFERENCE METHOD FOR DETECTING THE DIFFERENT STAGES OF CRACK PROPAGATION IN CARBON AND STAINLESS STEEL

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This paper reports on steel pressure vessels to establish the relationship between the growth of ductile cracks and acoustics emission (AE) produced during the different steps of crack propagation in laboratory specimens (plastic deformation, crack initiation and propagation).

To determine the efficiency of the AE method to detect the evolution of the cracks in carbon and stainless steel we have used a simultaneous monitoring of electric resistance and acoustic emission. Moreover, many parameters have been studied: acoustic parameters, potential difference, and SEM fractograph.

This study shows that AE characteristics of crack propagation depend on the category of steels and the different zones of propagation, as the base metals, the welds, and the heat affected zone (HAZ).

Keywords: Pressure vessels steel; acoustic emission; potential difference; cracks propagation.

INTRODUCTION

At present, pressure vessels are subject to extensive non-destructive testing, especially AE method. This method is one of the few techniques having the potential for a real time structural integrity evaluation.

However, before the AE inspection of pressure vessels becomes fully practical, it is essential to understand the acoustic emission behaviour of crack propagation in laboratory specimens.

This paper studies the relationship between the growth of ductile cracks in pressure vessels steel and acoustic emission produced during crack extension in CT specimens. It has been shown how is possible to detect the different stages of the damage over laboratory specimens of a pressure vessel material.

EXPERIMENTAL PROCEDURE

Materials and specimens

The work was carried out on two kinds of pressure vessels steels: the 304L stainless steel and the P265GH Carbon - Manganese steel.

In the present study, we examined three kinds of CT specimens, designated as specimen A, B and C. Specimen A was not welded, whereas specimens B and C were welded from top to bottom on the side and in the middle of the notch respectively.

The specimens were fatigue pre-cracked, this crack was introduced into different zone of metal following the CT specimens. In specimen A the crack was in the base metal, whereas in specimens B and C the crack was in the heat affected zone (HAZ) and the weld seam respectively (Figure 1).

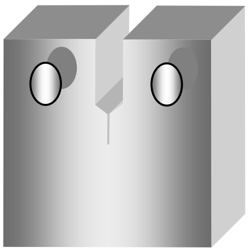
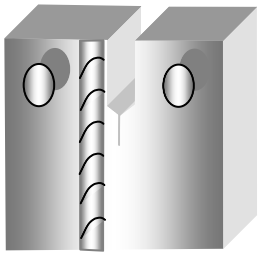
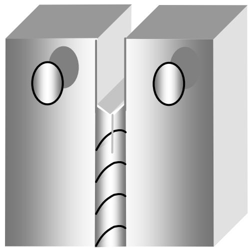
	SPECIMEN A	SPECIMEN B	SPECIMEN C
TYPES OF SPECIMENS			
POSITION OF THE CRACK	*Pre-crack in base metal*	*Pre-crack in HAZ*	*Pre-crack in weld seam*

Figure 1. Different kinds of specimens used during the tensile tests.

AE testing and electric method

Acoustic signals were detected by two kinds of piezoelectric sensors a wide band sensor (100 KHz to 900 KHz) and sensors with a resonance frequency of 150 kHz . The sensors were placed near the tip of the fatigue pre-crack. The acquired AE signals were amplified by a 40 dB fixed gain preamplifier. The threshold selected was 40 dB, which was well above machine noise level.

During the tests, electric method has been adopted together with the acoustic emission. To measure the potential difference, a direct current from source is passed trough the CT specimen. Potential contacts are placed at points 1, 2, 3 and 4. Point 1 is located near the end of the fatigue pre-crack and it's coupled with point 2, which is located on the opposite side of the specimen. Point 4 is on the same side as point 1 and it is coupled with point 3. This procedure was used and detailed by Ennaceur et al [1].

RESULTS AND DISCUSSIONS
Mechanics and electric results

The recording of the mechanics and electric results allows to distinguish the different stages of rupture as shown in figure 2 which reports the load required to initiate and propagate the crack, and the voltage curve measured during tensile test versus the displacement of the specimens C on P265GH steel.
The analysis of mechanics and electric results of the different kinds of specimens (A, B and C) and different steels (304L and P265GH) allows to obtain a chronological classification of different stages of damage in CT specimens.

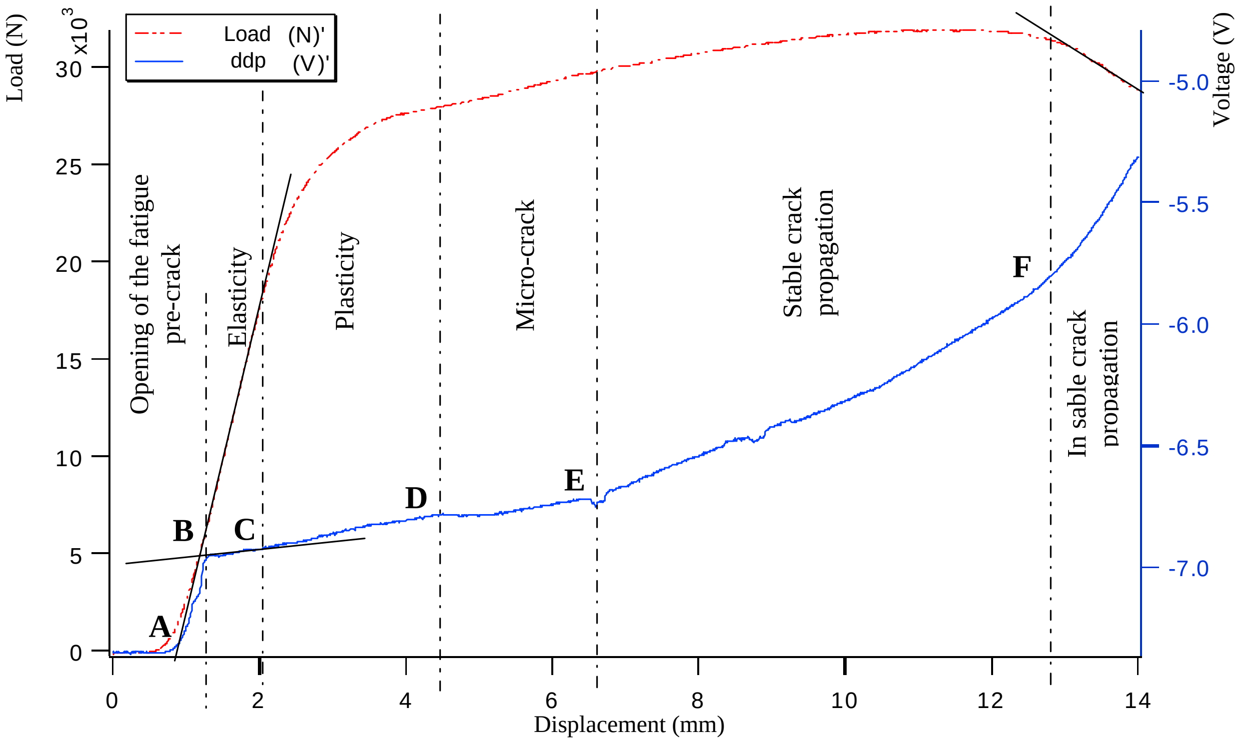


Figure 2 Voltage is plotted along with the load versus the displacement during the tensile test of specimen C on P265GH steel.

Acoustic emission response during the tensile test

The correlation between the results of electric method and acoustic emission techniques allows to differentiate every mechanism intervening during the crack propagation. The different sources of acoustic emission during crack propagation in 304L stainless steel and P265GH steel are:

- Plastic deformation: slip of dislocation in front of the crack tip;
- Micro-crack: creation of micro-voids in the plastic zone;
- Stable crack propagation : micro-voids coalescence ;
- Instable crack propagation.

Plastic deformation in front of the crack tip

The slip, which is the source of AE during plastic deformation, produces low amplitude continuous emission. Others have shown that there is very little acoustic emission generated during the tensile deformation of 304 stainless steel (James et al., [2], Heiple and Carpenter, [3] and Scuby et al. [4]). These results were confirmed by performing tensile tests on the 304L stainless steel used in this investigation. The data indicated that there is very little AE generated by the slip in our 304L stainless steel.

For example, the maximum amplitude recorded during this stage for the A specimen is 51dB.

Contrary to the 304L steel, the plastic deformation in CT specimens (B and C) on P265GH is characterised by an important acoustic emission. The analyses of the signals recorded during this deformation prove the presence of two sources of this AE:

- Plasticity 1 is the first source of acoustic emission. It presents the first motion of dislocation that produces a low amplitude continuous emission (64dB).
- Plasticity 2 is characterized by an important acoustic emission, which is significant in a number of events and amplitude (90dB in the case of the welding). This emission, caused by the energy liberated by the movement of dislocations, is emitted by peaks of signals (Figure 3). These peaks of acoustic activity correspond to co-operative movements of dislocations. Several studies concerning carbon steel confirm this result. Among these researchers, one quotes Ono et al. [5] worked specifically on carbon steels and concluded that the acoustic activity is very significant during the plastic deformation.

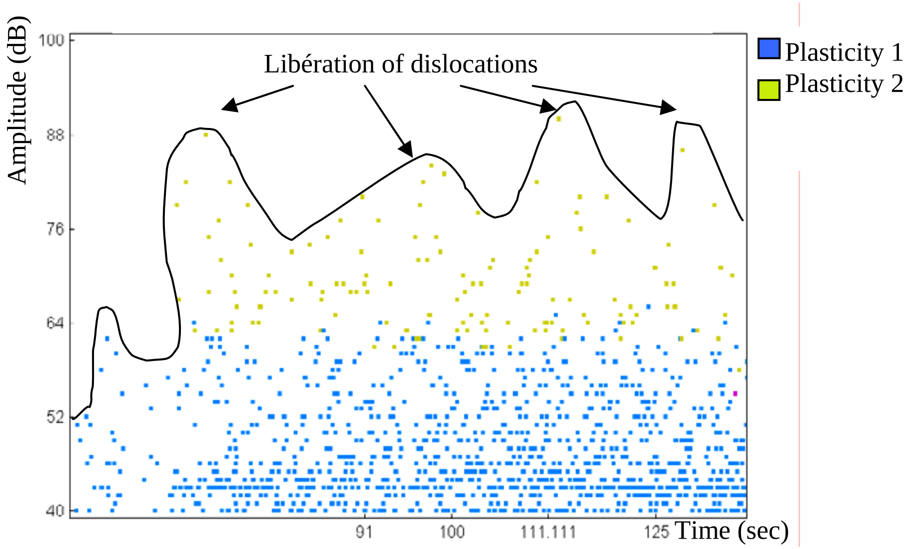


Figure 3. Plasticity1 and 2 during plastic deformation in the weld seam of CT specimens on P265GH.

In all specimens (in 304L steel and P265GH steel), along the plastic deformation, the most important acoustic emission was produced during the deformation in the weld seam. That means that the signature of this deformation depends of the heterogeneity and the ductility of the metals. The heterogeneity makes the movement of dislocations more difficult and more emissive because of the presence of a significant number of inclusions. The ductility reduces the periods of plastic instability, which constitute the principal sources of AE.
One can conclude that in these CT specimens acoustic emission is a suitable means of detecting the initiation (plastic deformation) of crack growth.

Micro-crack in the plastic zone

The source of the AE during this stage is the fracture and /or decohesion of the inclusions because they are generally very brittle, so they should be fractured very quickly.
The results of the two kinds of steel show that the acoustic emission signature of the micro-cracks mechanisms depends of the microstructure of the propagation zone (table 1). Table 1

shows the correlation between the micrography of specimens A, B and C of 304L and the AE recorded during their micro-cracking.

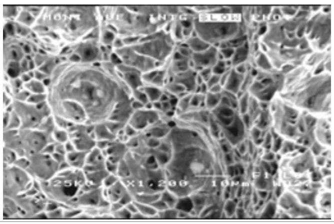
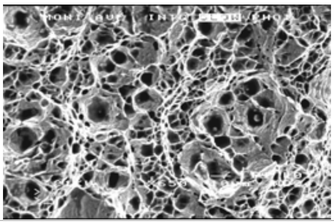
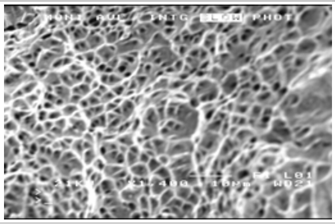
Base Métal	**HAZ**	**Weld seam**
		
Big and not deep dimples	Big and deep dimples	Small and deep dimples
3	**1**	**2**

Table1. Scanning electron micrograph of fracture surface in specimen A, B and C of 304L steel.

As shown in this fractography, the fracture surfaces of this material consist of dimples, which are the symbol of a ductile rupture. Careful scanning electron microscopy (SEM) examinations of the crack surface indicated that the dimensions of the dimples depend of the zone of propagation (base metal, HAZ or weld seam). So the acoustic signature of micro-crack depend of the dimensions and the deep of this dimples.
This result is important, because via this method of non-destructive testing, we can not only detect the physical mechanisms but also to know if micro-crack intervened in the base metal, in the ZAT or in the weld seam.

Stable crack propagation

The crack propagation proceeds primarily from micro-void coalescence (stable crack propagation) in AISI 304L stainless steel and P265GH carbon steel (figure 4). This mechanism forms the principle source of the AE recorded during this stage of crack propagation.

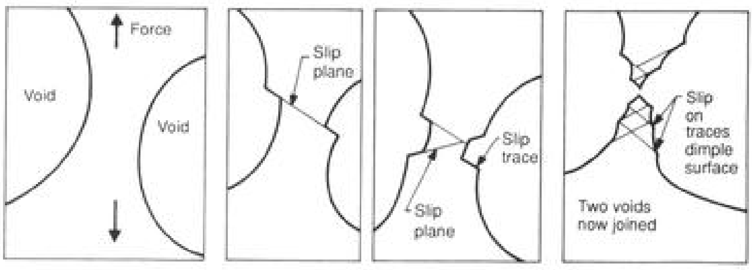


Figure 4. Crack propagation proceeds.

The AE measured during crack growth in the weld seam is characterised best by amplitude and energy, which are the most important features. These results are available for the 304L steel and the P265GH steel.
The table 2 shows how the acoustic signature of the stable propagation is also influenced by the microstructure of the propagation zone.

	Amplitude	*Micrography*
Spécimen A	2	Dimples not too close
Spécimen B	3	Dimples not too close
Specimen C	1	Very close dimples

Table 2. Amplitude of stable crack propagation signature and micrography of fracture surface in specimen A, B and C of 304L steel.

Contrary to micro-crack signature, SEM examination of fracture surfaces revealed that the acoustic signature produced by the coalescence of micro-voids depends of the distribution of the dimples in the material and not of theirs dimensions.
The ligaments separating the voids, joint easily before they have the possibility of growing. This scenario of brittle fracture confirms the importance of the amplitude of the signals emitted by the stable propagation in the weld seam.

COMPARISON OF THE ACOUSTIC SIGNATURE OF THE TOW KIND OF STEELS

The acoustic signature of the plasticity of the two types of steel is different. The plasticity of steel P265GH is more emissive and more energetic than the 304L steel. Contrary to carbon steel, the plasticity of the stainless steels starts with a very little acoustic activity and increases progressively with the crack propagation. This difference is due to the nature of the plasticity which is a homogeneous deformation for steel 304L and a heterogeneous plastic deformation for carbon steel P265GH.

The number of acoustic events recorded during the tensile test of the CT specimens on carbon steel is more important than that recorded for steel 304L, which is true in the weld or the HAT. Moreover, the most important acoustic parameters were recorded during the cracking of specimens on carbon steel. This phenomenon is due to the fact that steel 304L is much more ductile than carbon steel. The stainless steel amplifies the phenomena of plastic deformation and the resistance of the CT specimens. It has toughness superior to that of P265GH steel. This increase in toughness is accompanied by a greater discretion with regard to acoustic emission, because the periods of plastic instability, which constitute the principal sources of AE, are absent.

CONCLUSION

This investigation has shown the effectiveness of making AE measurements along with detailed metallographic and electric methods in determining the sources of acoustic emission during crack propagation in CT specimens on pressure vessels steel (304L and P265GH) and in comparison with the acoustic signature of the two kinds of steel.

The feasibility of using acoustic emission techniques to detect the different stages of ductile cracks propagation in laboratory specimen of 304L steel and P265GH steel has been shown. The identification of the acoustic signature of the different sources of the damage and the correlation with the micrography was based on the acoustic parameters like amplitude and energy.

The results of this study are on the scale of laboratory specimens; their extension to the structures would be very interesting to detect and locate the zone of the damage propagation and evaluate their severity in the pressure vessel in order to avoid their catastrophic ruptures.

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