



Modern concept of acoustic emission (AE) coupled with electrochemical measurements for monitoring the elastomer-coated carbon steel damage in phosphoric acid medium

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ABSTRACT

Elastomer coatings (rubber) are industrially used to protect phosphoric acid storage tanks against corrosion. Rubber constitutes a barrier against the penetration of H_3PO_4 to metallic surface. Coatings damage induces both acid infiltration and steel corrosion. In this concept, acoustic emission (AE) monitoring technique could be used for the detection of coatings damage as well as for steel corrosion under the coating. In the present work AE was coupled to electrochemical measurements (EM) for rubber damage evaluation and steel corrosion on three types of steels (XC48, E20 and A60) at room temperature in concentrated phosphoric acid (30% P_2O_5) contaminated by Cl^- , F^- , SO_4^{2-} . Electrochemical behaviour of steels was studied and characterized by potentiodynamic curves and polarization resistance measurement. A good correlation between acoustic emission and polarization resistance or corrosion potential measurements was found during stages of coatings damage and steels corrosion. The majority of AE activity recorded during experiments is related to hydrogen bubbles release. The release of hydrogen bubbles gives rise to two populations of signals: one impulsive and another one resonant.

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1. Introduction

The phosphoric acid is obtained in 95% of cases by wet process, from phosphate rocks attacked by sulphuric acid. This technique generates several corrosion problems caused by the presence of halides impurities in the hot phosphoric acid. During manufacturing process, reactors, pumps and phosphoric acid storage tanks are subjected to localized corrosion phenomena leading to steel material deterioration. Phosphoric acid carbon steel tanks are protected by elastomer coating. With the time, the infiltration of acid through the coating can cause steel corrosion. Materials used in acid environment must have good chemical and mechanical resistance. Lots of works have been carried out in order to characterize corrosion processes of steel in phosphoric acid environment [1,2].

In the present work, corrosion process of carbon steel covered or uncovered by elastomer coating was studied by acoustic emission (AE) techniques coupled to electrochemical measurements (EM).

Acoustic emission has been developed more than three decades ago, as a non-destructive evaluation (NDE) technique and as a useful tool for material research. Acoustic emission is defined as the

class of phenomena whereby transient elastic waves are generated by the rapid release of energy from localized sources within a material. Possible causes of the internal-structure changes are crack initiation and growth, crack opening and closure, dislocation movement, twinning, phase transformation in monolithic materials, fibre breakage and fibre-matrix debonding in composites. Most of the sources of AE are damage-related; thus, the detection and monitoring of these emissions are commonly used to predict material failure. AE is widely used for structural integrity monitoring. Many microscopic deformation or fracture processes have been studied with AE. AE is a highly sensitive technique for detecting initiation and cracks propagation [3]. Marrow et al. [4] investigated hydrogen cracking process of steels by means of AE. The AE was also employed by many researchers to study steel stress corrosion cracking [5–13] and pitting corrosion [14–18]. Recently phenomena of corrosion-abrasion [19], generalized corrosion [20] and exfoliation corrosion [21] were also studied by AE. The aim of this paper is to study and to monitor the corrosion of elastomer-coated or uncoated steels in phosphoric acid by AE associated with electrochemical techniques. On one hand, the first part of this paper consists in studying the corrosion behaviour of three carbon steels namely XC48, E20 and A60 at room temperature using electrochemical techniques. On the other hand, the main purpose of the second one is to correlate AE with electrochemical measurements

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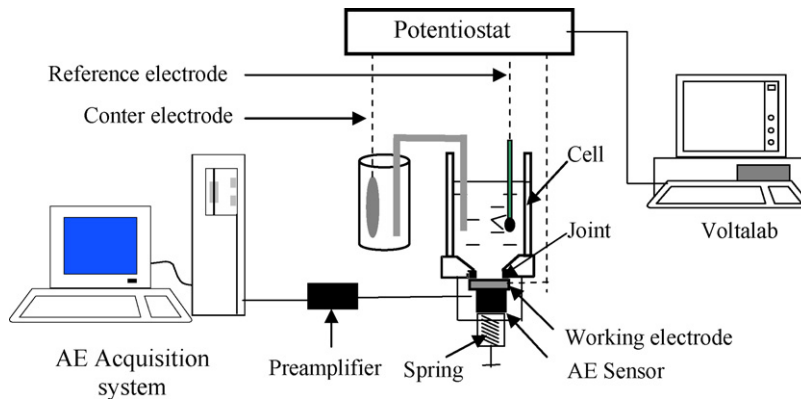


Fig. 1. Experimental device.

in order to study the corrosion processes of carbon steels protected or not by elastomer coating in phosphoric acid medium.

2. Experimental procedure

The experimental device used in this study is illustrated in Fig. 1. It comprises of the following.

A Pyrex glass cell test containing a steel sample; it is covered by an opaque layer of black painting to eliminate any light penetration, which can modify interactions in the metal/solution interface.

A potentiostat/galvanostat (RADIOMETER trade name) using the VOLTALAB version 3.10 software was used for electrochemical experiment. The steel sample (3 mm thick with a 55 mm diameter and its surface area of about 20 cm²), which represents the working electrode (WE), was polished mechanically on sand paper. The reference electrode is a saturated calomel electrode (SEC) and the auxiliary electrode is made of platinum mesh. AE instrumentation consisted of an acquisition card (MISTRAS), a preamplifier (EPA 1220A-gain 60 dB) and a piezoelectric ceramic sensor wide band (WD) which has a frequency range from 100 to 1000 kHz. The threshold applied for all AE measurements was 24 dB and the sample rate was 4 MHz. Through MISTRAS, all recorded signals can be characterized in real time as waveform, energy and amplitude. In order to assess steel corrosion, these waveforms need to be analysed in terms of frequency through the discrete Fourier transform (DFT) using Matlab software.

Table 1
Chemical composition of steels

Steels	C (%)	Mn (%)	P (%)	S (%)
XC48	0.45–0.51	0.5–0.8	≤0.035	≤0.035
E20	≤0.2	≤1.7	≤0.1	0.45
A60	≤0.22	≤1.3	≤0.025	≤0.025

The materials used are three ordinary steels coated or uncoated by elastomer. Chemical compositions of steels are listed in Table 1. They present identical metallographic structure made up of α ferrite phase and a lamellate phase of perlite (Fig. 2a). The choice of these steels was made on basis of their weldability. Indeed, both XC48 and E20 steel do not present a difficulty of welding, whereas A60 steel requires some care in order to not modify its mechanical properties. Elastomer has a more or less regular honeycomb structure (Fig. 2b) and a low density.

Elastomer coating was degraded naturally in the studied medium. This medium consists of 30% P₂O₅ mixed with 2% H₂SO₄ contaminated with 200 ppm of Cl⁻.

3. Results

3.1. Electrochemical behaviour

Electrochemical measurements were done independently of the acoustic measurements with the aim to study the corrosion process of these steels. Potentiodynamic curves (Fig. 3A) and polarization resistance (Fig. 3B) show that the corrosion of these steels in the phosphoric acid medium is governed by activation phenomena. In this case, the passage of the metal-atoms to ions in the solution is slowed either by the formation of unreactive layers or by the formation of a protective film. The polarization resistance measurement show that in this medium, XC48 steel corrodes 5 to 6 times more than A60 steel (Table 2). The polarization resistance for the later (Fig. 3B) shows an increase representing the formation of corrosion products layer that limits species diffusion and transport across the metal–solution interfaces.

3.2. Acoustic behaviour

The acoustic activity for XC48 steel increases with time (Fig. 4a), whereas for A60 steel this activity is quiet lower (Fig. 4b). However,

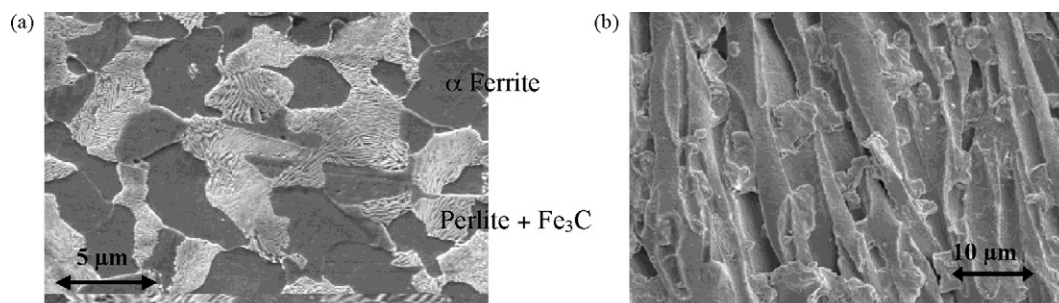


Fig. 2. Structure of steels (XC48, A60 and E20) (a) and elastomer coating (b).

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