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Acoustic emission technique to monitor crack growth in a mooring chain

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ABSTRACT

Mooring chains are designed for an operational life of 25 years. However, owner/operator data show that a Floating Production Unit (FPU) experiences a mooring line failure every 9 years on average, and periodic inspections are necessary to monitor their integrity. An established condition monitoring technique based on Acoustic Emission (AE) has the potential to be deployed to mooring chains. AE is based on the principle that elastic energy waves are spontaneously released by a material undergoing plastic deformation and crack growth. The purpose of this paper is to present a feasibility study of AE testing to monitor initiation and propagation of stress corrosion cracks in a mooring chain link, in order to establish whether crack initiation and crack extension phases can be detected and discriminated in the course of a static tensile test. The tensile test was carried out in artificial seawater (3% NaCl solution) using a single grade R5 link of diameter 160 mm for 3.7 months where a crack was initiated from a notch. AE features were plotted against time and these plots were extensively discussed with the view of contributing to the closure of a knowledge gap in the experimental literature.

1. Introduction

Mooring line systems of floating structures consists of long lengths of chains, rope or wire, see Fig. 1. Common practice is to combine wire rope of steel or synthetic fiber with heavy chains. Chains are typically used at the bottom and top of a mooring line to connect the anchor (thrash-zone), and the floating structure (splash zone) respectively. The zones are particularly exposed to corrosion, wear, axial load and in-plane and out-of-plane bending [1,2]. Hence, periodic inspections are necessary to monitor the health of these chains. The Health and Safety Executive (HSE) report [1] includes a survey of mooring failures. Based on data for the period from 1980 to 2001, it was reported that, a Floating Production Unit will experience a mooring line failure every 9 years on average.

Furthermore, one of the most common failure mechanisms seen in the mooring line of floating units is the failure of an individual chain, due to Stress Corrosion Cracks (SCCs) [1]. SCC is the cracking induced from the conjoint action of three components: a susceptible material, a specific chemical environment and tensile stress [3].

To ensure the integrity of structural materials, regular non-destructive inspections of chains are carried out. The state of the chain is monitored through a periodic inspection using nondestructive testing techniques such as the radiography, guided wave ultrasonic, etc. However, these techniques have certain limitations preventing them from adopting in continuous monitoring. Cracks can be detected only after they grow to certain relatively large size. Initiation of cracks can be missed if these techniques are adopted. For continuous monitoring, Acoustic Emission (AE) is one of the promising methods for detecting both initiation and propagation of stress corrosion cracks. Acoustic emissions are elastic energy waves that are spontaneously released by a material undergoing deformation or crack initiation and crack growth processes [4–6]. Acoustic emission technique is a potential structural health monitoring tool, which can serve as an early warning system for the offshore industry [4,7].

Many authors have used AE to monitor crack initiation and growth for different specimens of different structures. They found that AE features such as energy and counts can be correlated to estimate the crack growth rate. Han et al. [8] attempted to investigate the AE count behavior and source mechanism during fatigue crack propagation in a micro-alloyed steel specimen. The results showed that the acoustic emission was more sensitive to the changes in the fracture mode. In paper [9], AE during corrosion of 304 stain steel in H_2SO_4 solution with different pH values and Cl- concentrations was studied, it concludes that the evolution of hydrogen bubbles inside the pits is an AE source. AE signals are influenced by H_2SO_4 concentration. In [10] SCC of stainless steel 316L in Hank's solution is addressed and shown that the AE activity in the plastic region is caused by the rupture of an oxide film or salt cap formed over active pits by plastic deformation, or by the

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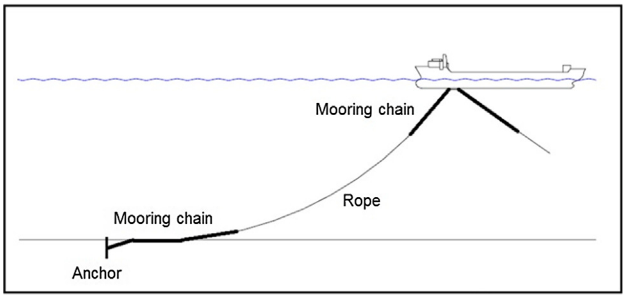

Fig. 1. Typical mooring system.

pressure build up in the pit due to trapped hydrogen bubbles. In [11], it is reported that several processes are responsible for acoustic emissions during SCC. These include metal dissolution, hydrogen gas evolution, breakdown of thick oxide film, fracture or decohesion of precipitate and inclusions, plastic deformation by slip or twin and micro/macro-cracking. In paper [12], AE was used for monitoring steel cracking during exposure to wet hydrogen sulfide environments. Two cracking phases were detected. The first was associated with decohesion of weak steel interphases. The second was identified as crack propagation under high internal hydrogen pressure.

Shaikh et al. analyzed acoustic emission signals to determine the micro process during SCC of AISI type 316LN stainless steel, [13]. According to this study, AE with amplitude ranging from 27 to 46 dB with different counts, energy and rise times occurred during SCC. AE was found to be continuous prior to crack initiation. The time gap between AE events increased during initiation. However, AE events occurred in burst during crack growth. Plastic deformation ahead of the crack tip was determined to be the major source of AE during propagation of SCC in type 316LN stainless steel.

It is noted that the authors in [11,14,15] measured the AE during the crevice corrosion SCC of type 304 stainless steel in a 3% NaCl solution using a double cantilever beam specimen with an artificial crevice. After inducing crevice corrosion by the polarization scan, the potential of the specimen remained constant and hydrogen gas evolved. The potential then increased to more positive values at the end of test. These authors reported that the gradient of the AE cumulative count curve changed greatly when the potential increased, but remained constant when the potential gradually decreased. The AE cumulative energy, however increased greatly in contrast to the above. It was stated that this sudden increment in AE energy corresponded to initiation of SCC and was caused by high amplitude AE signal.

It is important to note that in most of the work where the AE technique was used to monitor crack initiation and crack growth, testing was carried out on small specimens and for only short periods of time. It is well known that the behavior of AE signal is very different in small specimens and larger specimens due to the fact that many reflection are generated by the boundary conditions. In addition, it is expected the behavior of the AE features to be very different when considering long term testing.

The purpose of this paper is to present a feasibility study of AE testing in a test rig to monitor stress corrosion crack growth in a mooring chain link following application of a high tension load in a static manner. The objective of the test is to establish the time when SCC initiation takes place and how SCC propagates during a tensile test.

This paper is organized as follows. Section 2 covers the experimental setup where an overview of the AE monitoring set-up on a submerged chain link under uniaxial tension, the environmental conditions of the test rig, the types of sensors used and the way the threshold was selected to trigger the AE signals are described. Section 3 presents an overview of the AE features extracted during the chain tensile test. Section 4 describes a trial chain test which was carried out for a week to verify that the sensors and equipment were working correctly and to check the machine noise and environment noise levels associated with this particular test rig. Section 5 covers the loads applied during the full test, and the specific minimum break load and proof load applied by the chain manufacturer previously. Section 6 and 7 shows the results and discussion of following post-processing respectively, where three filters of peak amplitude were applied to the AE data, namely 45 dB, 55 dB and 65 dB. Each cumulative AE feature (energy, counts, duration, rise time, peak amplitude and hits) is plotted versus time, thus describing how fast the crack grows at the three recording threshold levels. Finally, Section 8 presents the general conclusions from the chain tensile test carried out so far.

2. Experimental set up of acoustic emission test

A full-scale static tensile test of a studless chain link under cathodic protection was carried out in seawater at TWI Ltd laboratories. The chain link was grade R5 steel (C 0.24, Si 0.2, Mn 2.2, Mo 0.26) [18] with a diameter of 160 mm. The test lasted circa 4 months (2780 h) in order to monitor SCC initiation and growth. SCC was initiated from a notch machined into the unwelded shank using an Electric Discharge Machine (EDM). The link delivered was proof loaded by manufacture before the tensile test according to the relevant codes and standards. This is to increase the service life of the link [2,16].

Fig. 2 shows an overview of the monitoring set-up, where a VALLEN AMSYS-6 AET system was used to record AE data. This is a multi-channel AE-measurement system with front-end software running on an external laptop. Each measurement channel consists of an AE-sensor, AE preamplifier and one channel of an ASIP-2 AE signal processor card [17].

Fig. 3 shows the test rig customized for this experiment. The link was submerged in 3.5% NaCl solution artificial seawater with cathodic

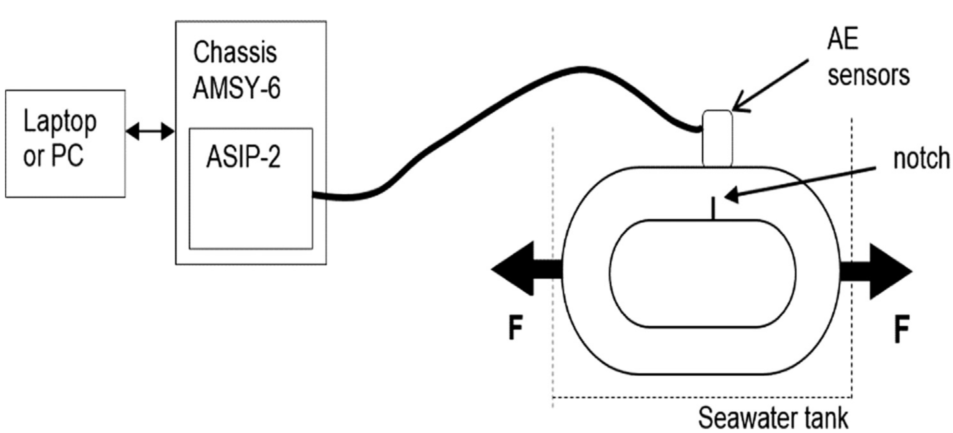

Fig. 2. Diagram of AE monitoring set-up on a submerged sensor and chain link under uniaxial tension.