Effect of Pitting Corrosion on Fatigue Life of Flexible Armor Wires

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ABSTRACT

Current industry practice in flexible pipe tensile armor wire fatigue testing involves use of un-corroded specimens; however, if the armor wires in a flexible are prone to pitting corrosion during service, this adds a new dimension to the fatigue life consideration which is the focus of this paper. The paper presents a methodology to consistently evaluate fatigue lives of armor wires with pitting corrosion. Described herein is a methodology to create corrosion pits on armor wires and the results from a fatigue test program involving Non-Pitted and Pre-Pitted specimens.

KEY WORDS: Flexible pipe risers; pitting corrosion; electrochemical pitting; corrosion fatigue; S-N tests;

INTRODUCTION

Flexible risers, used in the offshore Oil and Gas industry for hydrocarbon production and transportation, offer many advantages over steel pipes- the key one being their higher structural flexibility, and hence greater ability to accommodate dynamic loads in hostile offshore environments, especially those induced by vessel motions. A typical flexible riser consists of two sets of tensile armor wires helically wound around the inner pipe layers to provide structural strength for weight and dynamic loads. Fatigue of tensile armor wires used in flexible risers is often a consideration, from a design perspective as well as a remnant-life-assessment perspective.

The multi-layered flexible pipe cross section is a complex structure that can create unique operating conditions for the carbon steel armor wires in the annulus between the internal and external sheath. The annulus, which houses the armor wires, comprises the volume between the pressure sheath and the external sheath. The structure of flexible pipes is designed to prevent direct contact between the steel wires and external sea water, and between the steel wires and the internal produced fluid. Presence of liquid water or seawater in the annulus together with corrosive gases such as Carbon Dioxide (CO₂) and/or Hydrogen Sulphide (H₂S) can lead to wire corrosion; and under certain conditions, the presence of corrosive fluids in the annulus is possible either due to accidental damage of the outer sheath allowing seawater to enter the annulus, or due to condensation of diffused fluids from the inner bore. The corrosion in the annulus can manifest itself as general and pitting corrosion of the armor wires if the wires are not designed to resist such corrosive conditions in the annulus. Pitting corrosion is of particular interest since the pits, which can be as deep as 0.1 mm with aspect ratios in the range of 10 to 50, have the potential to initiate Stress Corrosion Cracking (SCC), Sulfide Stress Cracking (SSC) or Hydrogen Induced Cracking (HIC) in flexible flowlines under static load conditions, or fatigue cracks under dynamic load conditions in flexible risers. This assumes more importance when one considers the fact that thirty five percent of all flexible pipe damage incidents reported worldwide, according to the 2010 Sureflex JIP, is due to external sheath damage and annulus flooding.

Current industry practice (Andersen, 2003; Berge, 2003; Berg, 2008; Berge, 2014; Rubin, 2009) with respect to small scale fatigue tests involves the use of virgin tensile armor wire specimens and does not account for pitting corrosion. However, field observations indicate that wire pitting occurs fairly quickly, sometimes within a year, after annulus flooding. This implies that wires would need to resist fatigue under pitted conditions for the rest of the riser service life.

ExxonMobil has recently undertaken a test program to investigate the fatigue performance of tensile armor wires subject to pitting corrosion, by conducting small scale fatigue tests in air as well as in corrosive environments such as seawater and H₂S. Only the results of in-air tests are reported here; and it is anticipated that the other tests which are still ongoing will be presented in future publications. There are two novel aspects to the fatigue testing presented in this paper:

1. Armor wires were successfully pitted in a lab setting in a controlled manner representative of pitting that might occur in an in-field flexible pipe annulus, and the accelerated pitting methodology is described here. The pits on the Pre-Pitted specimens were created with a novel electrochemical pitting method, previously used only in stainless steels, to ensure control and repeatability over pit sizes- this allows for a systematic evaluation of the effect of pit sizes on fatigue lives, which has never been done before.

2. This is the first systematic assessment of the effect of pitting corrosion on fatigue lives of tensile armor wires, and builds on previous