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# Fractography of Crack Growth in Stress-Corrosion Cracking and Corrosion Fatigue of a Number of Offshore Steels

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## ABSTRACT

**Three steels (one 1 CrMoNb, one 3.5 NiCrMo and one 2.25 CrMo) which could be used in tethered buoyant platforms are assessed. Corrosion fatigue and stress corrosion tests in natural seawater containing sulphide-reducing bacteria have been made on each steel in various heat-treated conditions. Fractographs documenting the development of the cracking mode are presented. Intergranular, discontinuous-cleavage and microvoid coalescence are all observed at different times for the different steels. The relationship among the fractography, the microstructure of the steel and the applied stress intensity is investigated. Mechanistic models of crack growth are introduced and their relationship to observed fracture modes are discussed.**

## INTRODUCTION

The steels investigated in this paper are candidates for use in the tethering system of tethered buoyant platforms for deep water or marginal oil fields. The yield stress of the steels required for tubulars would be of the order of 800–1100 MPa (Cole et al., 1988). Such steels are likely to be susceptible to environmental damage. The results of the performance of the steels when subject to stress-corrosion cracking (SCC) and corrosion fatigue (CF) have been previously reported (Cole et al., 1988); however, this paper did not present the fractographic results nor discuss the micromechanisms of crack advance. If steels which resist environmentally assisted cracking are to be developed, then a detailed understanding of the relationship between microstructure and the micromechanisms of crack growth is required.

A number of workers have developed models for the micromechanism of crack advance both in SCC and CF. Some of these models are conflicting and experimental evidence is needed to assess the validity of such models. Thus, this paper presents the fractographic evidence derived from testing a variety of steels after a number of heat treatments. These results enable some correlations between fracture pattern/crack growth rate and microstructure to be established. A number of models are assessed against these results.

## MATERIAL AND EXPERIMENTAL PROCEDURE

The composition of the steels studied is given in Table 1. The steels were subjected to heat treatments (as received (AR), air cooled (AC), water quenched (WQ)) to produce a range of microstructures. The microstructures and mechanical properties of each steel following the heat treatments are given in Table 2.

Full details of experimental procedures are given in Cole et al. (1988). SCC and CF tests were carried out on each steel for each condition on three precracked single-edged notched specimens (14 × 55 × 165 mm) under three-point bending. All tests were carried out in an environment of natural seawater containing sulphide-reducing bacteria at a hydrogen sulphide concentration of 250 ppm. Crack growth was measured by standard direct current potential drop techniques. A stepwise loading program was carried out in SCC testing. The load was raised, so as to increase the stress intensity between 5 and 10 MPa$\sqrt{m}$, if the average crack growth over a period of $10^5$ s was less than $2 \times 10^{-10}$ m/s, this being defined as no growth. Experience showed that if growth did occur prior to $10^5$ s, the crack tip became blunted and crack initiation was not possible even if the load was raised significantly. CF testing was carried out at a frequency of 0.167 Hz and an R value of 0.6. Prior to fractographic analysis, specimens were cleaned in a solution of 5N HCl and hexamine powder.

## RESULTS

### Fracture Mechanics Parameters

The fracture mechanics parameters defining crack initiation and growth and the crack growth rate/stress intensity curves have previously been presented (Cole et al., 1988). These results are summarised in Table 2. Throughout the paper, K is always in MPa$\sqrt{m}$. In fatigue the stress intensity range ($\Delta K$) controls crack growth, but for the sake of comparison with the SCC data, K values are quoted in Table 3. The K values quoted for CF are the maximum K values of

| Steel | Percent weight | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | C | Mn | Si | Cr | Mo | Ni | V | Al | Nb |
| A. 1 CrMoNb | 0.13 | 0.69 | 0.24 | 1.04 | 0.74 | 0.06 | — | 0.029 | 0.026 |
| B. 3.5 NiCrMoV | 0.3 | 0.43 | 0.03 | 1.42 | 0.50 | 3.65 | 0.13 | — | — |
| C. 2.25 CrMo | 0.1 | 0.48 | 0.26 | 2.20 | 0.47 | 0.21 | — | — | — |

Table 1 Composition of steels

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KEY WORDS: Corrosion fatigue, stress corrosion cracking, fractography, sulphide-reducing bacteria, hydrogen embrittlement, fracture mode, tethered buoyant platforms.