Engineering Failure Analysis 47 (2015) 1–15

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Case studies in marine concentrated corrosion

M.N. James [a,b,*], D.G. Hattingh [b]

[a] Marine Science & Engineering, University of Plymouth, Drake Circus, Plymouth PL4 8AA, England, United Kingdom
[b] Department of Mechanical Engineering, Nelson Mandela Metropolitan University, Port Elizabeth 6031, South Africa

ARTICLE INFO

Article history:
Received 11 April 2014
Received in revised form 12 August 2014
Accepted 28 August 2014
Available online 16 September 2014

Keywords:
Marine concentrated corrosion
Accelerated low water corrosion (ALWC)
Intergranular corrosion (IGC)
De-alloying
Dezincification

ABSTRACT

This paper outlines the problem and analysis techniques in three exemplar case studies of marine concentrated corrosion. The intended audience is failure analysts or forensic engineers, who might occasionally come across examples of concentrated corrosion and are seeking relevant background information. In particular, it demonstrates the advantages in problem identification and solution that can accrue from the use of the highly sophisticated spectrographic instrumentation that is currently available. These techniques include energy dispersive spectroscopy (EDS) mapping in a scanning electron microscope (SEM), Fourier transform infrared (FT-IR) and Raman spectroscopy. Confocal laser scanning microscopy (CLSM) is also useful in surface metrology. The main case study presented is one of accelerated low water corrosion (ALWC) on the tubular steel piles of a marina. The paper includes an outline of some of the relevant literature relating to the use of these modern techniques in identifying marine corrosion products.

1. Introduction

Marine environments include a number of ‘zones’ in which materials may be exposed and suffer corrosion, i.e. atmospheric, splash and spray, tidal, immersion, or submerged and bottom sediment [1]. Metals are widely used as structural materials in these various environments and there are a multitude of factors which influence the rate and severity of corrosion mechanisms, including temperature, nutrient level, water velocity and depth.

In terms of their effect on structural integrity, marine corrosion problems range from localised issues affecting individual ship or marine fittings, for example shackles, bolts and chains, to much more severe issues associated with phenomena such as accelerated low water corrosion (ALWC) of port structures.

The present paper gives an introductory outline of marine corrosion issues and influential factors before focussing on specific case study examples of ‘concentrated’ corrosion chosen as exemplars of interesting mechanisms where the use of modern techniques and instrumentation is useful in their identification and prevention. The case studies chosen comprise two examples of classic problems, namely intergranular corrosion of stainless steel, and dealloying (dezincification) of α–β brass. Whilst these are well known mechanisms of corrosion, some more recent work has advanced understanding of mechanisms and of alloy design to mitigate their influences; it therefore seems useful to review some of this work in the context of case studies.

The paper then goes on to present an outline of the more interesting case of accelerated low water corrosion (ALWC) of steel piling on a harbour structure. ALWC is a topic of significant current interest in Europe [2–5]. As noted in the summary sections of Refs. [3–5], it is a particularly aggressive form of localised corrosion on marine structures which occurs typically

* Corresponding author at: Marine Science & Engineering, University of Plymouth, Drake Circus, Plymouth PL4 8AA, England, United Kingdom.

http://dx.doi.org/10.1016/j.engfailanal.2014.08.013
1350-6307/

at, or below, the low water level in tidal and brackish water. It is a form of Microbiologically Induced Corrosion (MIC) that leads to unusually high rates of metal wastage (a corrosion rate perhaps in the order of 0.3–1.0 mm/wetted side/year) and holing, potentially leading to loss of backfill for sheet piling, structural weakening and other integrity problems on much shorter timeframes than envisaged in the original structural design. It is known to affect port structures, in particular steel piling, and is a global phenomenon that is currently detected via visual inspection. Typically, ALWC is evidenced as lightly adherent orange patches localised in a narrow band above Lowest Astronomical Tide (LAT) or occasionally extending down to bed level. Under these orange outer layers, a black sludge can be observed which covers a bright and extensively pitted steel surface (Figs. 1a and 1b). If timely remedial action is not taken, extensive and expensive (and unbudgeted) repair and maintenance works may have to be undertaken. Fig. 2 illustrates typical corrosion loss rates on steel structures as a function of the marine environment zones and shows the ALWC zone.

The ALWC case study in this paper will cover identification of the problem, the choice and implementation of remedial works, and the subsequent observation and identification of a thick calcareous deposit which forms on steel piles above the high water mark under cathodic protection. It is emphasised that this case study should be seen in the forensic context of marina operators involved in litigation with the design consulting engineers, and who were seeking to understand the problem that they faced and the necessary remedial measures.

2. Marine corrosion

The topic of marine corrosion has received significant attention in the literature, e.g. [1], and the intention here is simply to briefly recall several key issues about marine environmental zones and corrosion rates and to point the reader to some of the relevant literature. Table 1 summarises data given in BS 6349-1 [6] for typical uniform corrosion rates on structural steels in a temperate environment, as a function of the marine environment zones. Corrosion rates in excess of these values can be caused locally by several forms of accelerated or 'concentrated' corrosion, which include:

- Galvanic or bi-metallic corrosion where one metal is connected to a more 'noble' metal, i.e. one with a more positive electromotive force (EMF) value, or where weld metal is significantly less noble than the parent plate. A particular form of galvanic corrosion occurs as localised corrosion at grain boundaries caused by the anodic dissolution of (i) regions depleted of alloying elements, (ii) second phase precipitates, or (iii) regions with segregated alloying or impurity elements. This is known as intergranular corrosion which can occur in pure metals or engineering alloys [7] and will be demonstrated in this paper through an example observed on 316 stainless steel shackles used to attach a buoy to riser chain on a river mooring point. Dealloying is another form of selective electrolytic dissolution of a less noble metal from a metallic solid solution or intermetallic compound [8] and will be illustrated in a case study of dezincification of α–β brass studs used to attach copper sheathing to the hull of a sailing yacht.
- Microbial activity in concentrations around and below the low water zone leading to a particularly aggressive form of concentrated corrosion that has become known as accelerated low water corrosion (ALWC) and which, as noted above, is a mechanism of increasing concern to port and waterway authorities around the world, as well as to marina or berth owners. The forensic case study outlined in this paper relates to tubular steel piles used to construct a marina on the South Coast of the UK.

Immersion corrosion is also influenced by a number of other factors, including temperature, nutrient level in the water [9], compositional variations [10] and seawater-related issues such as salinity, dissolved oxygen content and pollutants such as sulphides [1]. Melchers discusses the influences of low levels of nutrient pollution on corrosion in Ref. [9] and the effect of elevated nutrient level in Ref. [11]. Inorganic nutrients such as nitrogen and phosphorous occur in inland and coastal waters

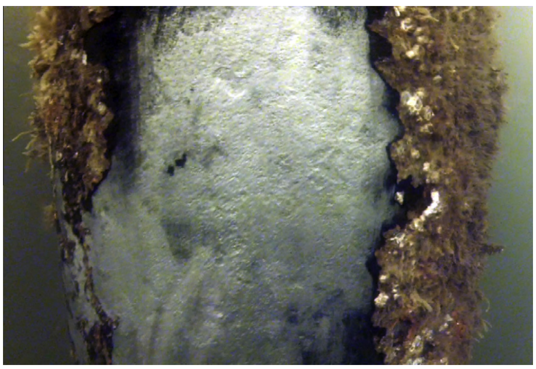

Fig. 1a. Typical appearance of ALWC observed during a diving inspection underwater – bright appearance of the steel under a lightly adherent orange and black deposit.