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Detection and analysis of microbiologically influenced corrosion of 316 L stainless steel with electrochemical noise technique

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ABSTRACT

Microbiologically Influenced Corrosion (MIC) is a specific type of corrosion caused or promoted by microorganisms usually chemoautotrophs. In recent years, there has been growing interest in the exploitation of electrochemical noise technique to investigate and monitor biocorrosion. The advantages of Electrochemical Noise (EN) technique includes the possibility to detect and study the early stages of localized corrosion; however the comprehension of EN signals still remains very limited. In the present work an attempt has been made to analyze the current and potential noise records for type 316 L stainless steel (SS) specimen immersed in Iron oxidizing bacteria inoculated medium amended with different concentrations of NaCl. All the potential and current noise data collected in the time domain were transformed in the frequency domain, using MATLAB software. Shot noise parameters like frequency of corrosion events (f_n), average charge in each event (q), true coefficient of variation and noise resistance (R_N) were analyzed. Low frequency events and high charge were observed for the specimen after the exposure of 3 weeks in microbial medium with 1% NaCl when compared to control. It indicates that microbes can influence the pitting corrosion over the specimen which was also evidenced by Scanning Electron Microscope (SEM). In addition to this, the probabilistic failure model for MIC on 316 L SS was predicted using Weibull distribution.

1. Introduction

Corrosion can be defined as the deterioration of physical properties of the metal due to a reaction with its environment (air, moisture, acids etc.) [1]. Microbiologically-Influenced Corrosion (MIC) is a specific type of corrosion of metals as a result of the metabolic activity of microorganisms [2]. There are about a dozen of bacteria, fungi or algae known to cause MIC of carbon steels, stainless steels, aluminum alloys and copper alloys in waters and soils with pH 4–9 and temperature 10–50 °C. In general, microorganisms secrete metabolites such as mineral and organic acids, exopolymers that can influence pitting, dealloying, galvanic corrosion, stress corrosion cracking and hydrogen embrittlement [3–5]. This MIC is extremely aggressive, and in its worst form, leads to failure in heat exchanger systems, fire protection systems, cooling water pipes, petroleum transmission pipes and offshore structures etc. [6–8]. Once established, MIC is difficult to eliminate, and may elevate into a chronic maintenance and operating problem for years following.

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Due to the electrochemical nature of MIC, electrochemical methods are useful tools to study reactions at the metal/biofilm interface, investigate MIC mechanisms and monitor the onset of MIC and its propagation. Several researches have attempted to understand the MIC phenomenon by the use of linear polarization resistance, galvanic currents, potentiodynamic polarization curves, large signal polarization techniques, random potential pulse method, electrochemical noise technique, electrochemical impedance spectrometry and electrochemical relaxation methods (programmed pulse relaxation, sinusoidal ac relaxation) [9,10].

Electrochemical noise is defined as the random fluctuations of the potential and current passing through an interface under the potentiostatic or galvanostatic control, typically of low frequency (<10 Hz) and low amplitude [11,12]. Data analysis of ECN can give information about the rate and nature of the chemical process taking place at the electrodes. This technique has been used to study the equilibrium constant of redox reaction and homogeneous process in solution [13]. This noise analysis is well developed in chemistry, biology and electronics and is being increasingly applied to electrochemical systems, particularly in corrosion engineering [14]. Electrochemical Noise (EN) under open-circuit potential has emerged as an alternative technique for corrosion studies since it does not require input signals that could cause perturbations to operating systems [15]. EN technique measures the stochastic fluctuations of the corrosion potential and the corrosion current. It also gives information about the kinetics and mechanism of the corrosion process [16]. Hence, this technique can be used for online monitoring of corrosion caused by microbes even when the operating system is active.

To elucidate this, iron oxidizing bacteria (IOB) was chosen as a model organism. Metal depositing bacteria (iron oxidizing bacteria) are capable to generate energy for growth by oxidation of ferrous (Fe^{2+}) to ferric (Fe^{3+}) ion, that afterwards precipitate as ferric hydroxides ($Fe(OH)_3$) extracellularly [17]. Little and Wagner reported that the acceleration of the corrosion process by IOB on stainless steel and other passive metals was prone to crevice corrosion [18]. It is known that corrosion damage occurs in different steel equipments, heat exchangers (tubes, lids, tube-sheets, connection pipes, extinguisher pipelines) and other parts of the water system in oil refinery and nuclear plants mainly by IOB [19]. Severe pitting attack (pit depth up to 10 mm) was detected on the SS due to IOB beneath the brownish rust sediment layer [20].

Hence, in this study, an attempt was made to use electrochemical-noise parameters to detect the initiation and propagation of MIC on stainless steels. It is also aimed to analyze the electrochemical potential noise (EPN) and electrochemical current noise (ECN) data for the prediction of corrosion kinetics using shot noise theory. In addition, the effects of different concentrations of NaCl (1%, 3% and 6%) on MIC were also discussed using EN technique.

2. Materials and methods

2.1. Specimen preparation

The specimen used in this study was AISI Type 316 L SS (UNS S31603) obtained from Steel Mart India, Mumbai and its chemical composition is shown in Table 1. Prior to the experiments, the cylindrical rod specimens were abraded with wet silicon carbide papers up to 1200 grit, then rinsed with deionised water, degreased with acetone and finally dried in air. For EN studies, cylindrical shaped AISI Type 316 L SS (length: 0.035 m, diameter: 0.020 m) drilled and tapped at one end in order to prevent crevice corrosion attack were used.

2.2. Microorganism and media

Iron oxidizing bacteria was isolated from sea water using a selective medium containing (per L distilled water) 0.15 g glucose, 0.5 g ammonium sulfate, 0.01 g calcium nitrate, 0.05 g dipotassium phosphate, 0.05 g magnesium sulfate, 0.05 g potassium chloride, 0.10 calcium carbonate, 0.0001 g cyanocobalamin (Vitamin B12) and 0.0004 g thiamine. The oxidation of Fe^{2+} to Fe^{3+} by the IOB isolate was confirmed by the appearance of the characteristic deep red color when potassium thiocyanate (KSCN) was added to the broth [21]. For EN studies, the IOB was inoculated in a nutrient medium (per L sterilized distilled water, pH 7): 5.0 g peptone, 1.5 g beef extract, 1.5 g yeast extract amended with different concentrations of NaCl (1%, 3% and 6% w/v). The medium amended with different concentrations of NaCl without IOB served as the control.

2.3. Electrochemical noise studies

Electrochemical noise studies were performed on a PC-controlled electrochemical analyzer (CH Instruments, 660D, Austin, USA). The electrochemical cell consisted of a two nominally identical working electrodes (one working electrode is directly connected to ground and the other is connected to the working electrode cable) and Silver/Silver chloride

Table 1
Chemical composition of 316 L stainless steel.

Element	C	Si	P	S	Cr	Mn	Fe	Ni	Mo
Weight%	0.01	0.98	0.04	0.03	17.02	1.98	65.25	11.18	3.51