Electrochimica Acta 203 (2016) 416–425

Contents lists available at ScienceDirect

Electrochimica Acta

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

Microstructure and corrosion behaviour of deformed pearlitic and brass-coated pearlitic steels in sodium chloride solution

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ARTICLE INFO

Article history:
Received 30 August 2015
Received in revised form 29 February 2016
Accepted 1 March 2016
Available online 2 March 2016

Keywords:
Pearlitic steel
Brass
Microstructure
Corrosion
Deformation

ABSTRACT

The microstructure and corrosion behaviour in 0.1 M NaCl of the brass coating and solid brass are first determined. Obtained results indicate that their microstructure plays a significant role in dezincification and in the kinetics of the oxygen reduction. The results suggest that the coating is significantly affected by plastic deformation (microstructure, thickness). The corrosion behaviour of the pearlitic steel and the brass-coated pearlitic steel is then investigated after plastic deformation. The coating breakdown happens at a critical concentration of vacancies generated by dezincification in the ultra-thin parts of the coating. The substrate is then exposed to the solution. Hydrolysis of Fe^{2+} induces a pH decrease, which can promote dezincification and then dissolution of the coating. Plastic deformation increases sharply the corrosion susceptibility of the pearlitic steel.

1. Introduction

Pearlitic carbon steels are used in numerous applications (including rails, ropes for bridges, elevators, high-strength wires, concrete structures . . .) where high strength, wear resistance, ductility, toughness, and low cost are important [1–3]. Brass can be used as coatings on steels to improve their corrosion resistance while maintaining all usable advantages offered by steels. Brass-coated steels are used in several industrial sectors to produce springs, brushes, hose reinforcement, tyres, electrical cables . . .

A review of the literature indicates that low attention has been paid to the influence of microstructure on the corrosion behaviour of pearlitic steels. AFM observations at the microscale have shown in sodium chloride solutions a preferential attack of the ferrite phase and the cementite acting as a cathode [4]. In a previous paper [5], we found that the pitting potential of pearlitic steels in 0.05 M NaCl at 25 °C depends on the grain orientation spread. This parameter can be quantified by means of electron backscatter diffraction measurements. Low attention has also been paid to the influence of mechanical deformation on the corrosion behaviour of pearlitic steels. It has been noticed that pearlitic prestressing steel (designed and prepared according to the ASTM standard A416) exhibits high corrosion susceptibility in alkaline solutions containing low chloride amount (0.25 M) [6]. It has been shown that cold drawning dramatically affects the environmentally assisted cracking performance of pearlitic steels [7–10]. In a previous paper, we demonstrated [11] that the corrosion rate of pearlitic steels in 0.1 M NaCl is significantly affected by plastic deformation.

Several studies [12–14] have revealed that brass-coated steels are subjected to corrosion in sodium chloride solutions. The successive steps involved in the corrosion of brass coatings have been identified by means of zero resistance ammeter tests, namely passivity, dissolution of the native zinc oxide ZnO and dissolution of brass with preferential dezincification [11]. If the coating does not completely cover the surface, corrosion occurs on the uncoated steel areas together with brass dezincification [15]. It has also been shown [15,16] that enrichment of copper in the coating induced by dezincification leads to an increase of the cathodic current. Galvanic coupling between steel and brass coating affects significantly the corrosion rate of the brass-coated pearlitic steels in 0.1 M NaCl at 25 °C [11]. Yet, the specific role of the microstructure of the brass coating on the electrochemical response and corrosion behaviour of the brass-coated steel is not fully understood.

In this paper, the microstructures of brass coating and solid brass (both having the same chemical composition Cu68Zn32 and the same crystallographic structure α-phase are first compared by means of electron backscatter diffraction (EBSD). The electrochemical behaviours of both systems are then determined in 0.1 M

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http://dx.doi.org/10.1016/j.electacta.2016.03.005
0013-4686/

NaCl at 25 °C using electrochemical impedance spectroscopy (EIS). The role of the microstructure of brass in the cathodic and anodic reactions is then discussed. The corrosion behaviours of the pearlitic steel and the brass-coated pearlitic steel are then investigated after plastic deformation in 0.1 M NaCl at 25 °C. Degradation mechanisms are discussed.

2. Experimental

2.1. Material and surface preparation

Experiments were carried out on pearlitic steel rods. The chemical composition of this alloy (wt%) was: 0.69–0.73% C, <0.02% S, <70 ppm N, <0.02% P, 0.1–0.3% Si, 0.4–0.6% Mn, <0.05% Cr, <0.01% Mo, <0.05% Cu, <0.01% Al, bal. Fe. Samples were first degreased in acetone for 15 minutes under ultrasonic and then dried under air flow. Cu68Zn32 brass coating was then formed on a set of rods by electrodeposition. Experimental conditions for the electrodeposition can be found in [17]. The chemical composition of the coating was determined by means of scanning electron microscopy and X-ray photoelectron spectroscopy. For comparison purpose, solid brass with the same chemical composition and the same crystallographic structure (α-phase) was also studied (provided by Goodfellow under the reference CU020650). Plastic deformation was applied to both coated and uncoated rods. The deformation level reached was estimated to $\varepsilon = 3.59$ according to Eq. (1).

$$\varepsilon = \ln (D_0/D)^2 \quad (1)$$

where D_0 is the initial diameter of rods and D the final diameter.

2.2. Surface observations

Surface observations were performed using a field-emission scanning electron microscope (FE-SEM, JEOL JSM-7600F) coupled with the silicon drift detector (SDD)-X-Max from Oxford Instruments (detector size of 80 mm^2 for EDS analyses) and with the TSL EDAX OIM XM4 EBSD system. This microscope operated at 20 kV

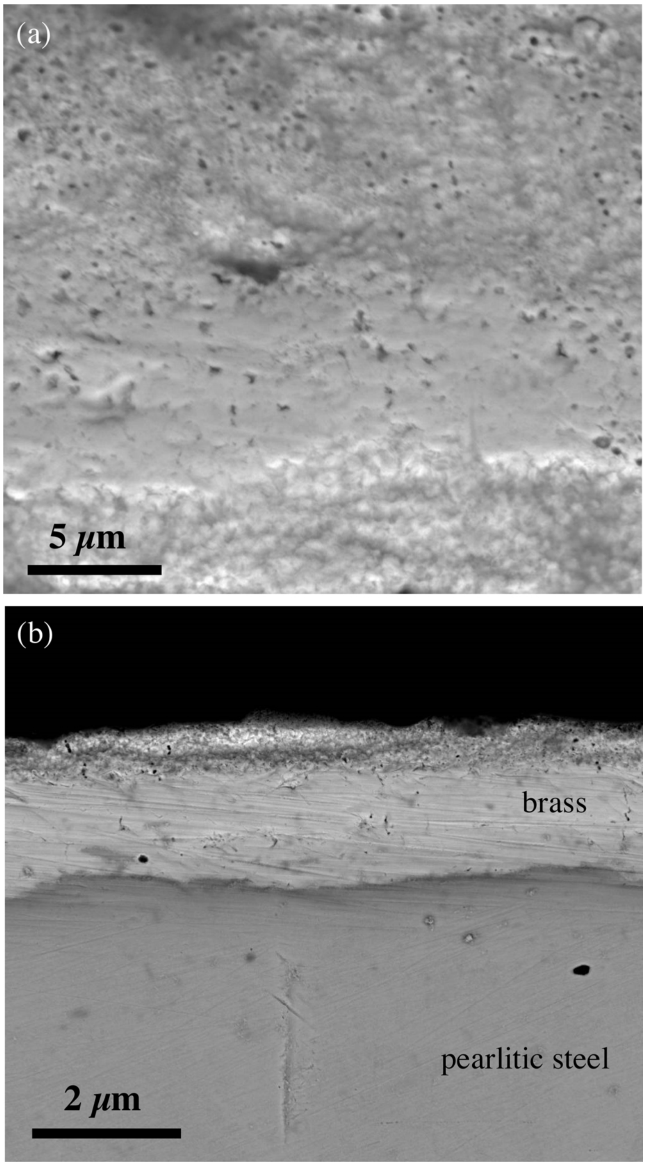

Fig. 1. FE-SEM images of the brass-coated pearlitic steel: (a) Top-view and (b) side-view. No plastic deformation was applied.