Electrochimica Acta 124 (2014) 165–175

Contents lists available at ScienceDirect

Electrochimica Acta

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

Corrosion study on Al-rich metal-coated steel by odd random phase multisine electrochemical impedance spectroscopy

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ARTICLE INFO

Article history:
Received 19 March 2013
Received in revised form
26 September 2013
Accepted 28 September 2013
Available online 19 October 2013

Keywords:
Odd random phase multisine
Al-rich metal-coated steel
Corrosion
Data modeling
Statistical evaluation

ABSTRACT

Galvanized steel is widely used in transportation and industry. However, the corrosion performance of these products is highly affected while exposed to chloride-containing environments. One alternative is Al-rich metal coatings which are known to notably improve the corrosion protection of the steel substrate by the enhanced barrier properties provided by Al. Although hot dip aluminum-based coatings on steel are nowadays used for many applications, little is known about the electrochemical behaviour of these coatings.

This work studies the corrosion behaviour of Al-containing metal coated steel. Odd random phase multisine electrochemical impedance spectroscopy (ORP-EIS) is used for monitoring the corrosion evolution under continuous immersion in a NaCl solution. This technique allows a rapid screening of corrosion processes due to the reduced measurement time with respect to conventional single sine techniques. Extra information concerning linearity, stationarity and noise level is also supplied and can be valuable for further data quality evaluation and fitting. Different equivalent electrical circuits are proposed and their validity is discussed, not only based on physical phenomena but also taking the quality of the obtained data and the statistical evaluation of the fittings into account.

1. Introduction

The addition of aluminum to zinc galvanized steel products is a well established practice in the steel industry. These products not only face important cost reductions – due to the increasing price of zinc in the last years – but they respond to the market's demand for more versatile materials [1]. The improved performance of Zn/Al coated steel products lies on the enhanced corrosion protection in many industrial and marine environments for aluminum additions up to 4–5 wt.% [1–3]. The synergy between the barrier properties of aluminum and the stabilization of adherent corrosion products has been pointed out as the reason for the improved corrosion performance of Zn–Al coated steel versus galvanized steel [1,4,5].

Although hot dip aluminum-based coatings are nowadays widely used for building and domestic applications, little is known about their electrochemical behaviour. In the PhD thesis of Schoukens [6], different conventional and local electrochemical techniques were proposed to study the effect of silicon additions to hot dip aluminized coatings. As a result, a link was established between the microstructure and the electrochemical behavior in different aqueous solutions.

A wide number of corrosion studies on hot dip galvanized and hot dip Al–Zn steel can be found in the literature [1,5,7–12]. Different corrosive environments are considered: chloride and sulphate containing solutions [7–11], accelerated corrosion tests [1,12], outdoor exposure [1,5]. Single sine electrochemical impedance spectroscopy (EIS) is used to develop an equivalent electric circuit (EEC) describing the different physical phenomena taking place in all the studies mentioned.

The aim of this work is to study the corrosion behaviour of Al-rich metal-coated steel. In this frame, an approach is presented towards the in situ corrosion study by ORP-EIS. The principle of this technique is based on the implementation of an odd random phase multisine excitation signal. As a result, the level of disturbing noise, the level of the non-linear distortions and the level of the non-stationary behaviour can be measured and quantified. The use of one excitation signal implies a notable decrease of the measurement time with respect to conventional single sine techniques. This is crucial for the rapid screening of highly dynamic systems, i.e., systems exposed to corrosive environments. The theoretical background can be found in [13–15].

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http://dx.doi.org/10.1016/j.electacta.2013.09.159

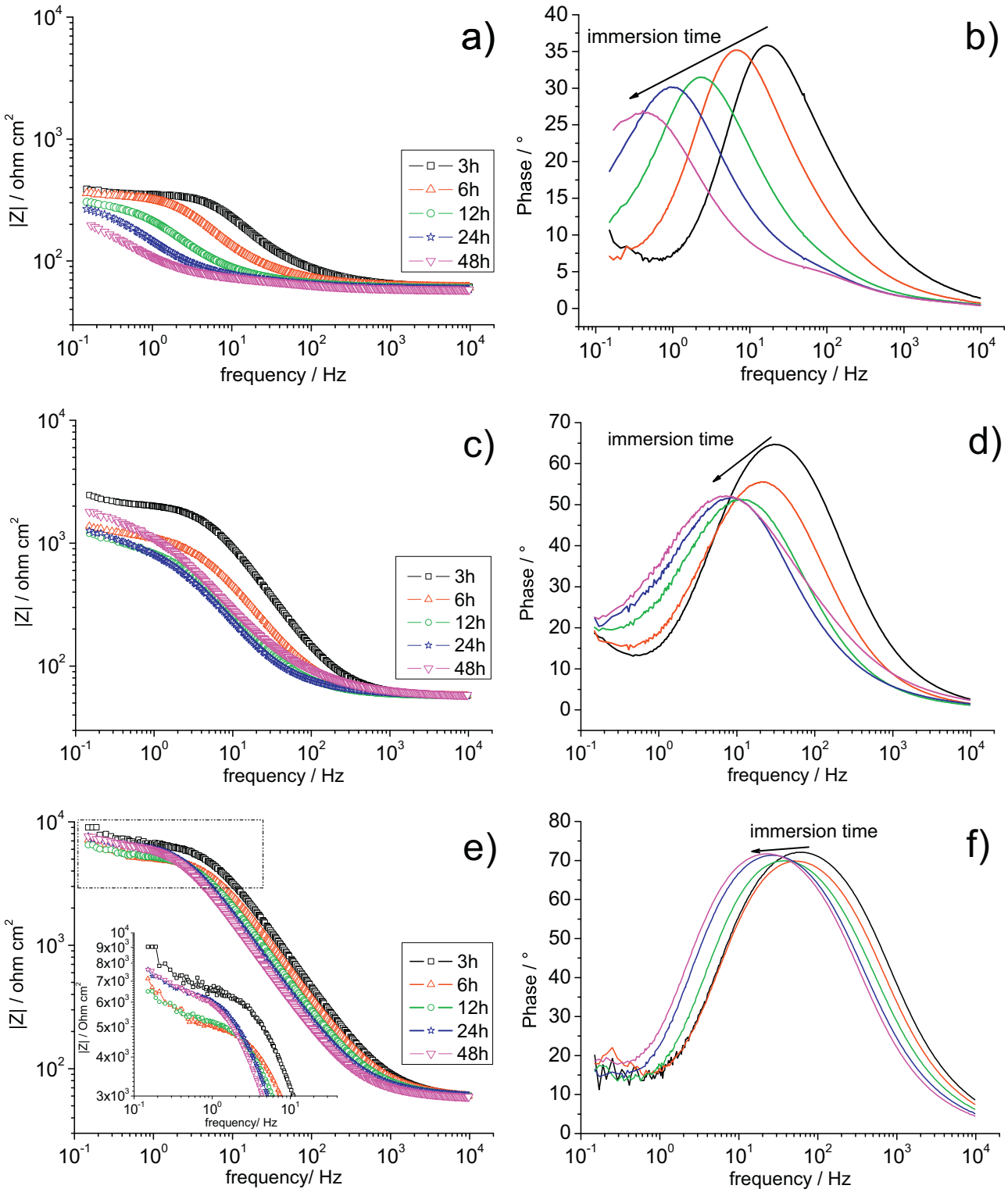

Fig. 1. Bode plots of hot dip galvanized steel (a) and (b), hot dip Al–Zn (c) and (d) and hot dip Al (e) and (f) after 3, 6, 12, 24 and 48 h of immersion in 0.05 M NaCl.

From the measurements obtained, a model is built up in the form of an equivalent electrical circuit. The statistical treatment of the measured data is then applied to evaluate the reliability of the proposed model and the quality of the obtained data. A physical interpretation is derived based on the evolution of corrosion under continuous immersion in 0.05 M NaCl and the observations made on the surface before and after exposure by scanning electron microscope (SEM). The effect of the aluminum content is studied and discussed. For this aim, three different systems with varying Al content in the metal coating (between 0.5 and 100 wt.%) have been selected.

2. Experimental

Three different industrial metal-coated steel systems were studied. The metal coating compositions were: 99.5 wt.% Zn and 0.5 wt.%