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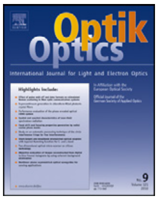

Measurement of surface resistivity/conductivity of metallic alloys in aqueous solutions by optical interferometry techniques

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ABSTRACT

Optical interferometry techniques were used for the first time to measure the surface resistivity/conductivity of the pure aluminium (in seawater at room temperature), UNS No.304 stainless steel (in seawater at room temperature), and pure copper (in tap water at room temperature) without any physical contact. This was achieved by applying an electrical potential across the alloys and measuring the current density flow across the alloys, during the cyclic polarization test of the alloys in different solutions. In the mean time, optical interferometry techniques such as holographic interferometry were used in situ to measure the orthogonal surface displacement of the alloys, as a result of the applied electrical potential. In addition, a mathematical model was derived in order to correlate the ratio of the electrical potential to the current density flow (electrical potential/electronic current flow = resistance) and to the surface (orthogonal) displacement of the metallic samples. In other words, a proportionality constant (surface resistivity or conductivity = 1/surface resistivity) between the measured electrical resistance and the surface displacement (by the optical interferometry techniques) was obtained. Consequently the surface resistivity (ρ) and conductivity (σ) of the pure aluminium (in seawater at room temperature), UNS No.304 stainless steel (in seawater at room temperature), and pure copper (in tap water at room temperature) were obtained. Also, electrical resistivity values (ρ) from other source were used for comparison sake with the calculated values of this investigation. This study revealed that the measured value of the resistivity for the pure aluminium ($7.7 \times 10^{10}\ \Omega$ cm in seawater at room temperature) is in good agreement with the one found in literature for the aluminium oxide, 85% Al_2O_3 ($5 \times 10^{10}\ \Omega$ cm in air at temperature 30 °C). Unfortunately, there is no measured value for the resistivity of cupric oxide (CuO), cuprous oxide (Cu_2O), or even the oxide of the UNS No.304 stainless steel in literature comparing those values with the measured values in this study.

1. Introduction

In a previous work conducted by the author [1], a mathematical model was derived in order to relate the electrical resistance of the oxide film on a metal sample (surface) to the thickness of the oxide film on the metal sample. The mathematical model can be described as the following:

$$R = \frac{\rho U_{\text{total}}}{A} \tag{1}$$

where R is the electrical resistance of the oxide film (Ω). ρ is the electrical resistivity of the oxide film (Ω cm). A is surface area of the sample (cm^2). U_{total} is the total thickness of the oxide film which can be obtained by holographic interferometry, a non-contact technique (μm).

U_{total} can be determined as the following:

$$U_{\text{total}} = \frac{N\lambda}{\sin\alpha + \sin\beta} \tag{2}$$

where N is the number of fringes. λ is the wavelength of the laser light used in the experiment, for He–Ne laser light ($\lambda = 0.6234\ \mu$m). α is the illumination angle ($\alpha = 47.23°$). β is the viewing angle ($\beta = 90°$), both α and β can be obtained from the set up of the experiment.

A detailed derivation of Eqs. (1) and (2) is given elsewhere in literature [2,3].

Eq. (1) has been used to obtain the electrical resistance of aluminium oxide film, Al_2O_3, on pure aluminium samples in different concentrations of sulphuric acid solutions by using optical interferometry techniques [1].

Eq. (1) also can be used to measure the surface resistivity/conductivity of metallic alloys in aqueous solutions. This can be achieved by laser holographic interferometry in order to measure the total surface orthogonal displacement, U_{total}, during the

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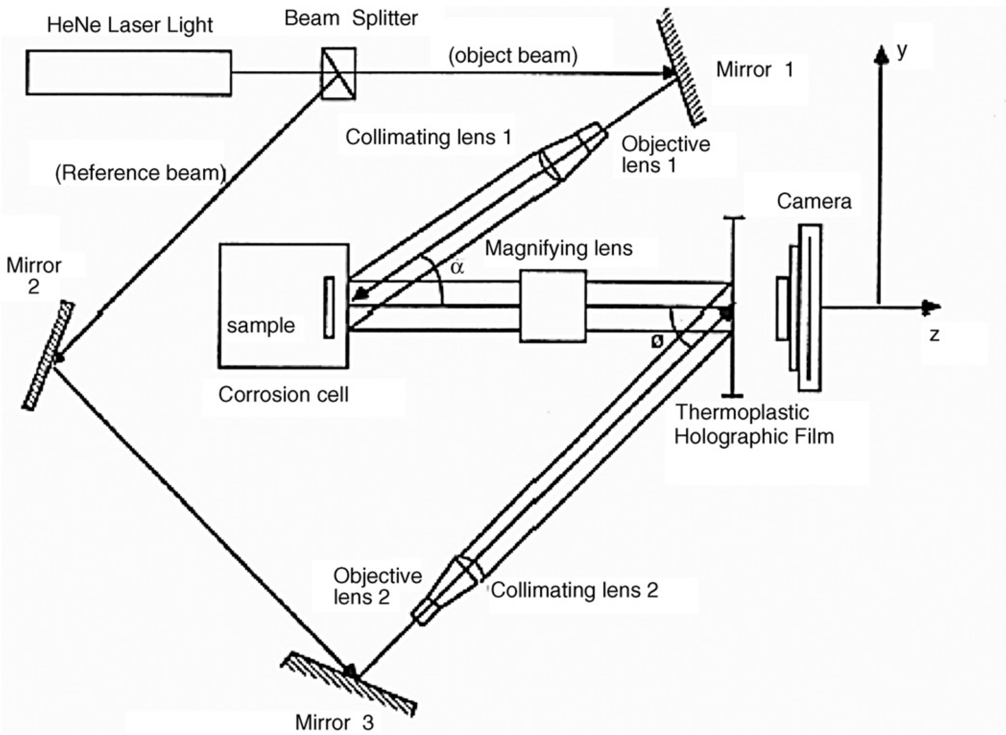

Fig. 1. Optical setup of an off axis holographic interferometry.

electrical polarization of the metallic alloys in the aqueous solutions, from Eq. (2). This implies that an electrical potential will be first applied on the metallic alloys. Then the produced current density flow across the metallic alloys, as the result of the electrical potential, will be measured. Eventually, a correlation can be developed, from Eq. (1), between the ratio of the applied electrical potential to the current density flow (electrical potential/current density flow = resistance × area) and to the surface (orthogonal) displacement (U_{total}) of the metallic alloys, from Eq. (2). In other words, a proportionality constant (surface resistivity = ρ or conductivity = $1/\rho = \sigma$) between the measured electrical resistance and the total surface displacement (by the optical interferometry techniques) can be obtained. Consequently the surface resistivity/conductivity of the metallic alloys can be determined, without any physical contact.

2. Experimental work

Metallic samples of pure aluminium (99.7% Al), UNS No.304 stainless steel (18–20% Cr, 8–11% Ni, 2%max Mn, 1%max Si, and 0.08%max C) and pure copper (99.8% Cu) were used in this investigation. The pure aluminium samples were fabricated in a cylindrical form with dimensions of 8 cm in diameter and 0.15 cm in thickness. The rest of the samples was fabricated in a rectangular form with dimensions of 10.0 cm × 10.0 cm × 0.15 cm for this investigation. Then all samples were polished and ground by silicon carbide papers until the finest grade (1200 grade) was reached. In order to be sure that the aluminium samples have attained scratch-free surface, the samples were etched by a chemical solution for 2 min at temperature ranged between 85 and 95 °C. The etching solution made of 3 g/L of sodium hydroxide + 30 g/L of tri-sodium phosphate. Then a coal tar (black) epoxy (polyamide cured) was used on one side and all edges of all samples. The reason for covering one side and all the edges of the samples by the coal tar epoxy is for protection from the solutions while testing the other side of the samples (side exposed to solution). At the beginning of each test, each sample was immersed in a particular solution for 1 h. While the sample was in the solution, the corrosion potential was monitored by a voltmeter with respect to a Saturated Calomel Electrode (SCE), reference electrode. After the sample attained steady state corrosion potential, a hologram of the sample was recorded using an off axis holography, see Figs. 1 and 2 for the optical set up. In the meantime cyclic polarization was conducted on the sample with the hologram recording of the sample in the solution. In this study, a camera with a thermoplastic film was used to facilitate recordings of the holographic interferograms of the samples. The camera is HC-300 Thermoplastic Recorder made by Newport Corporation. Also, in this study, a potentialstat model 273 made by EG&G Princeton applied research was used to conduct the cyclic polarization test for determining the surface resistivity/conductivity of the three metallic alloys in different aqueous solutions. During each experiment, the holographic interferograms were recorded as a function of time, in which each test lasted for less than 60 min, the duration of cyclic polarization of the samples in solutions. Then, the interferograms were interpreted to an orthogonal displacement of the surface of the metal by using Eq. (2). Also, by knowing the applied potential for

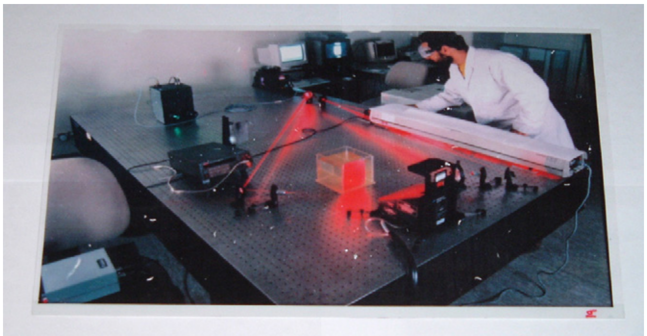

Fig. 2. A photograph image of the laboratory of the off axis holographic interferometry.