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Evaluation of transit stray current interference by optical interferometry methods

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Abstract

It is well known that a metal solid in an electrolyte solution would develop an electrochemical potential difference a cross the interface between the solid and the solution. The electrochemical potential is normally called the open circuit potential (OCP). As a result, exchange currents, cathodic (Ic) and anodic (Ia) currents, will form due to chemical reversible reactions between the metal solid and the solution,. The chemical reactions can be either cathodic or anodic reaction. If the cathodic exchange current (Ic) is more than the anodic exchange current (Ia), therefore, a net exchange current would form toward the cathodic polarization of the solid in the solution. This is also a true case during the cathodic protection of the solid in the solution. An excess of cathodic current on the solid metal might lead to the phenomenon of stray current and subsequently to transit stray current interference. In the present work, an evaluation of a transit stray current of a low carbon steel, pure aluminum, a stainless steel, and a copper–nickel alloy in 1M NaOH, 1M KCl, 1M NaCl, 1M H_2SO_4 solutions, respectively, was conducted by an optical interferometry technique. A transit stray current was solely detected by the optical interferometry of the pure aluminium sample at the open circuit potential of the sample in 1M KCl solution. An excessive measured value of the corrosion current density, 19,625.8 $\times 10^{-6}$ A/cm^2, was determine for the pure aluminium sample in 1M KCl solution as compared to the rest of the alloys in solutions. In contrast, the average noise of current/time measurements of the Galvanic coupling between two similar samples of the pure aluminum in 1M KCl solution was found to be the lowest, 4.22$\times 10^{-6}$ µA/cm^2 by the zero resistance ammeters, among the rest of the alloys in solutions.

Keywords: Low carbon steel, 1M NaOH solution, Corrosion, Transit stray current, Optical interferometry.

1. Introduction

It is well known that electronics instrumentation, i.e. ammeter, Potential-meter, have been used for years to measure electrochemical properties of metallic electrodes in aqueous solutions. One of the disadvantages of using electronic instruments for the measurement of electrochemical properties is the invasive nature of those instruments to the electrochemical systems of the metallic electrodes in aqueous solutions. In recent works published elsewhere[1-12], it has been shown that laser optical interferometry can be used as an optical transducer to characterize the electromagnetic field, i.e. phase and amplitude of the reflected light waves of a surface of a metallic electrode moving further away from the light source, which develops as a result of the electron conduction in metallic electrodes in aqueous solutions due to the anodic reaction, corrosion processes, between the electrodes and the aqueous solutions. The characterization of such electromagnetic field (phase and amplitude of the reflected light waves of a surface) and a mathematical correlation of the electromagnetic field to any electrochemical properties, i.e. corrosion current density, double layer capacitance, alternating current impedance, and so on, would lead to the measurement of the electrochemical properties by optical interferometry, by the non-invasive method.

The objective of the present work was to evaluate the corrosion current density of a low carbon steel (UNS, a pure aluminum, a stainless steel, and a copper–nickel alloy in 1M NaOH, 1M KCl, 1M NaCl, 1M H_2SO_4 solutions, respectively, by the holographic interferometry technique. Furthermore, the work aimed to compare the obtained data of the corrosion current density of the optical interferometry with other techniques of the corrosion measurement such as the zero resistance ammeter and linear polarization method [13-14]. It is well known that the zero resistance ammeter and linear polarization method [13-14] are widely used to measure the corrosion current density of metallic electrodes, which corresponds to the open-circuit potential of the electrodes in aqueous solutions. In the zero resistance ammeter, one can measure the corrosion current density of two similar metallic electrodes at the open-circuit potential of the electrodes in an aqueous solution without imposing any external voltage on the electrodes. This normally occurs due to the presence of the electronic noise and the absence of the electrical resistance across the interface between two similar electrodes and the aqueous solution, in the mechanism of the zero resistance ammeter. Consequently, measurements of corrosion current density of metallic electrodes by the zero resistance ammeter are much higher than other techniques, because of the presence of electronic noise and the absence of the electrical resistance across the interface between the solid electrodes and the aqueous solution. On the contrary, in the linear polarization method, one can measure the corrosion current density of a metallic electrode at the open-circuit potential of the electrode in an aqueous solution by imposing an external voltage on the electrode. As a result, a polarization resistance normally develops across the interface between the solid electrode and the aqueous solution. This leads to extremely low measurements of the corrosion current density of the electrodes in aqueous solutions, because of the presence of the polarization resistance in the mechanism of the linear polarization method.

2. Materials and methods

In the present investigation, metallic alloys of a low carbon steel (UNS No. 1020, 0.2% C, 0.45% Mn, 0.25% Si, and balanced Fe), a pure aluminum (99.7% Al), a stainless steel (UNS No. 304 stainless steel, 19% Cr, 9% Ni, 0.45% Mn, and balanced Fe), and a copper–nickel alloy (70% Cu and 30% Ni) were used in 1M NaOH, 1M KCl, 1M NaCl, 1M H_2SO_4 solutions, respectively. The samples were fabricated in a plate form with dimensions of 10.0 cm x5.0 cm x 0.15 cm. Then all samples were polished and ground by silicon carbide papers until the finest grade (1200) was reached. Then a coal tar (black) Epoxy (polyamide cured) was used on one side and all edges of the samples. The reason behind covering one side and all edges of the samples by the coal tar Epoxy is for protection from the solutions while testing the other side of the sample (exposed side to solution) to corrosion. The exposed surface area of the sample is 45 cm^2. At the beginning of each test, a sample of the above materials was immersed in a specific solution for 1 h. while the sample in the solution, the corrosion potential was measured by a potential-meter with respect to the saturated calomel electrode (SCE), a reference electrode. After the first hour of the immersion, a hologram of the sample was recorded using an off axis holography optical set up [1-2].

In this study, a camera with a thermoplastic film was used to facilitate recordings of the holographic interferometry of the samples. The camera is HC-300 Thermoplastic Recorder made by Newport Corporation. During each experiment, the holographic interferograms were recorded as a function of time, in which each test lasted for 60 min. Then, the interferograms were interpreted to orthogonal displacement of the surface of the metal. Thereafter, the displacement measurements are used [1-2] to determine the corrosion current density of the samples. Finally the obtained data of the corrosion current density of all metallic samples are compared with other data produced by the electronic zero-resistance ammeter and by the linear polarization method on the same samples in the specified solutions. In this study, a potentialstat made by EG&G Princeton Applied Research was used to measure the corrosion current density, data, by the linear polarization method, using EG&G model 352 corrosion analysis software. In contrast, a potentialstat/Galvanostat made by ACM instrumentations, the ACM Gill 860 system, was used in this investigation to determine the average noise of the potential/time and current/time of a Galvanic coupling between two similar samples in the specified solutions. It is worth noting that there was no delay time at the beginning of each test during the measurements of the average noise of the potential/time and current/time of the Galvanic coupling between two similar samples. Also, in order to plot the potential/time and current/time of the Galvanic coupling, the duration of the recorded data between each sequence reading was 0.7 s, and lasted for 15 min. In this study, the zero resistance of the ACM Gill 860 system was used to determine the corrosion current density which corresponds to the open-circuit potential of the samples in solutions. Finally the obtained data of the corrosion current density of all metallic samples by the optical interferometry were compared with other data produced by the other methods.

3. Results and discussion

Figure 1 shows an example of progressive interferograms of a carbon steel sample in seawater as a function of time. Fig. 1a represents a real-time interferogram of the sample after 10 min of the elapsed time of the corrosion test, where six fringes appeared on the photograph. Fig. 1b is the same interferogram after 14 min of elapsed time of the corrosion test, where 10 fringes detected on the photograph. It is obvious from these interferograms in Fig. 1a and b that there is a uniform chemical oxidation, depicted by the interferometric patterns. These observations of Fig. 1a and b are in agreement with interferograms documented on metallic electrodes in aqueous solutions, elsewhere [2]. It is worth mentioning that each fringe in Fig. 1 (dark line) accounts to an orthogonal displacement equivalent to 0.3 µm according to mathematical models reported elsewhere [2]. Also, there are neither gas formation nor a significant variation in the refractive index were observed at the samples during the optical interferometry measurements. In other words, holographic interferometry can be used as a powerful tool, interferometric microscope, in the field of electrochemistry.

By using data from interferograms such as those in Fig. 1, one can measure the corrosion current density of metallic electrodes in aqueous solutions by holographic interferometry..

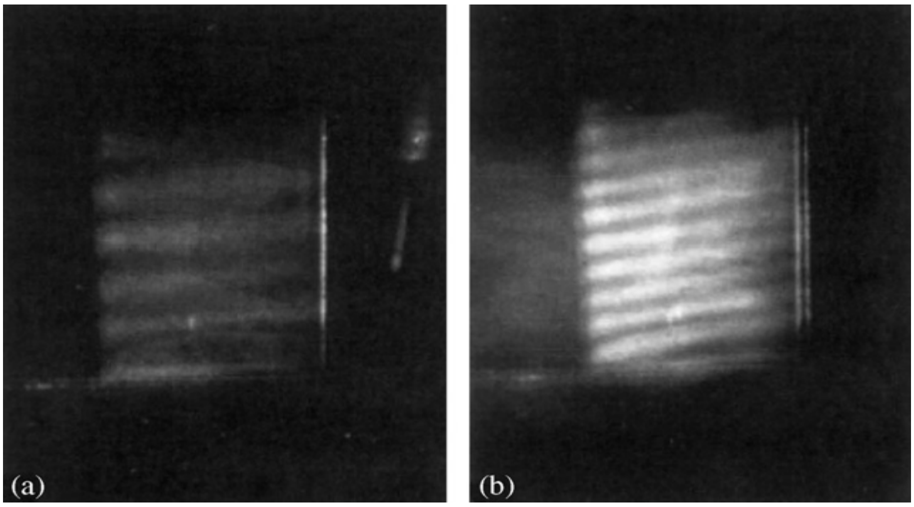

Figure 1. An example of progressive interferograms of a carbon steel sample in seawater as a function of time: (a) after 10 min and (b) after 14 min.

An example of the average noise of current/time and potential/time measurements of a Galvanic coupling between two similar samples of the low carbon steel is shown in Fig. 2a and 2b, respectively. The average noise value is based on two readings of the current density of the Galvanic coupling as a function of time.

The average noise of the current/time was found to be 0.037, 4.22×10^{-6}, 0.042, and 0.1004 $\mu A/cm^2$ for low carbon steel, pure aluminum, stainless steel, and copper–nickel alloy, respectively. It is obvious that the average noise values of the current/time of all samples tend to yield a zero value as a function of time, due to the low Galvanic coupling current between the two similar metallic samples (see Figs. 2a). In addition, the values of the average noise of the potential/time of two readings tend to converge to a steady-state value as a function of time (see Figs. 2b). A comparison between the corrosion data of the metallic samples with respect to the three methods of the corrosion measurement are given in Table 1.

In general the tabulated data indicate that there is a contrast between the corrosion data which is measured by the three methods. For instance, the electronic zero-resistance ammeter was found to give the highest corrosion values for all the samples investigated in this study compared to the linear polarization method. In contrast, the linear polarization method was found to give the lowest corrosion values for all the samples investigated in this study at the open-circuit potential of the samples in solutions. On the other hand, the optical interferometry method was found to give corrosion values fall in between the values of the corrosion data of the zero resistance ammeter and the linear polarization method. The high values of the corrosion data by the electronic zero-resistance Ammeter can be readily explained due to the functional nature of the low electrical resistance in this technique as well as to the electronic noise which is involved in the process of the measurement of the corrosion current density.

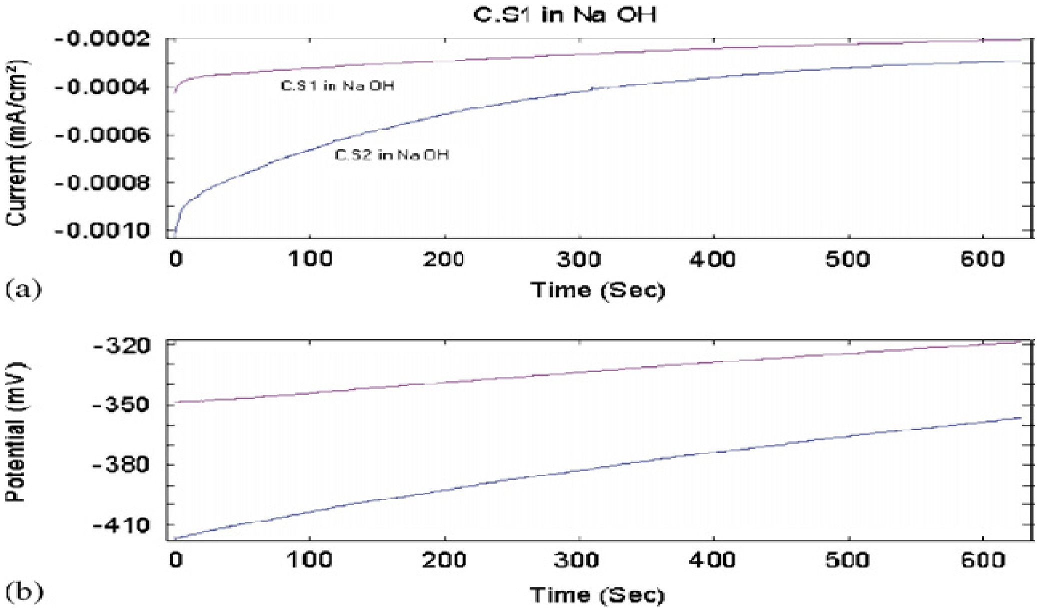

Figure 2. The average noise of the current/time (a) and potential/ time (b) of a Galvanic coupling between two samples of the low carbon steel in 1M NaOH.

Table 1. Comparison between the corrosion values of the four metallic samples by different methods of corrosion measurement (corrosion current density 10^{-6} A/cm^{2})

Materials	Optical interferometry	Zero resistance ammeter	Linear polarization
Low carbon steel	23,024.5	19,617.8x10^{3}	6.2
Stainless steel	13,400	6,554,300	0.02
Aluminum	19,625.8	3600	3.2
Copper–nickel alloy	11,060.3	73,951x10^{3}	9.25

In contrast, the extreme low values of the corrosion data by the linear polarization method is due to the presence of the polarization resistance in the mechanism of the linear polarization method. It is possible that the corrosion values of the optical interferometry fall in between the corrosion values of the zero resistance ammeter and the linear polarization method because the technique works based on the electromagnetic principle in the absence of electronic noise. In other words, the optical interferometry can be considered as a non-electronic zero-resistance-ammeter which works by an electromagnetic mean rather than an electronic mean. This implies that the optical interferometry comprises neither electrical resistance nor electronic noise, as compared to the other techniques used in this investigation. The excessive measured value of the corrosion current density of the aluminium sample by optical interferometry (19,625.8 x10^{-6} A/cm^{2}) as compared to the other techniques probably due to the fact that aluminium oxides so rapidly in 1M KCl solution. Consequently, the potential of the aluminium shifts toward the cathodic direction because of the formation of Al$_2$O$_3$ film, leading to a higher current density. This excessive measured current can be considered as a transit stray current that was detected by solely the optical interferometry technique at the open circuit potential of the sample in 1M KCl solution. In contrast, the average noise of current/time measurements of the Galvanic coupling between two similar samples of the pure aluminum in 1M KCl solution was found to be the lowest, 4.22x10^{-6} µA/cm^{2} , by the zero resistance ammeter, among the rest of the alloys in solutions.

It is worth noting that the corrosion current density in Table 1 was determined based on an average of two readings for the zero resistance ammeter, the optical interferometry, and the linear polarization methods.

Conclusions

1. The electronic zero-resistance ammeter was found to give the highest corrosion values for all the samples investigated in this study compared to the optical interferometry and linear polarization method. The high values of the corrosion data by the zero resistance Ammeter can be readily explained due to the functional nature of the low electrical resistance in this technique as well as to the electronic noise which is involved in the process of the measurement of the corrosion current density.
2. In contrast, the linear polarization method was found to give the lowest corrosion values for all the samples investigated in this study at the open-circuit potential of the samples in solutions. This is because of the presence of the polarization resistance in the mechanism of the linear polarization method.
3. It is possible that the corrosion values of the optical interferometry fall in between the corrosion values of the zero resistance ammeter and the linear polarization method because the technique works based on the electromagnetic principle, with the absence of electronic noise.
4. The excessive measured value of the corrosion current density of the aluminium sample (19,625.8 $x10^{-6}$ A/cm^2) can be considered as a transit stray current that was detected only by the optical interferometry at the open circuit potential of the sample in 1M KCl solution.
5. In contrast, the average noise of current/time measurements of the Galvanic coupling between two similar samples of the pure aluminum in 1M KCl solution was found to be the lowest, $4.22x10^{-6}$ $\mu A/cm^2$, by the zero resistance ammeter, among the rest of the alloys in solutions.

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