Experimental Design in the Study of Physical and Chemical Variables in Galvanic Corrosion between Carbon Steel and CuAlBe

M. C. P. Cruz^a, C. M. F. Soares^b, R. T. Figueiredo^b; E. B. Cavalcanti^b, R. E. Souza^c, P. M. M. Araújo^d

^a Faculdade Pio Décimo, Av. Tancredo Neves, 5655, Sergipe-Brasil
^b Instituto de Tecnologia e Pesquisa, Av. Murilo Dantas, 300, Sergipe-Brasil
^c Petrobras, Rua Acre, 2504, Sergipe-Brasil
^d Departamento de Engenharia mecânica, UFS, Sergipe-Brasil

The behavior of galvanic corrosion between carbon steel and CuAlBe with Shape Memory Effect was investigated using the technique of Zero Resistance Amperometry (ZRA), in an electrolytic environment that simulates the water produced from mature oil fields. For this purpose, we used a fractional factorial design $2^{6\cdot 2} + 6$ central points with the following variables: Cl⁻, SO₄⁻, S⁻, HCO₃⁻, ratio of anodic area to cathodic area (1:1, 1:½, 1:½) and temperature (25, 35 and 45 °C). The anodic dissolution current was measured as a time function. The results present evidence that the anodic dissolution current is directly proportional to the anodic area in complex electrochemical fluid.

Keywords: Galvanic corrosion, carbon steel, CuAlBe, Shape memory alloy

Introduction

In exploration and refining the petroleum industry is faced with a wide variety of conditions and, normally, requires a determined technological study. When one observes the corrosion in this industrial sector, these rules continue to hold true. The electrolytic environment is a complex, highly saline, aggressive environment, containing CO_2 and H_2S . The interaction between dissolved salts, corrosive gases and suspended solids, together with the hydrocarbons and water obtained in the oil fields, results in a synergetic phenomenon of degradation of metallic materials still not entirely understood [1, 2]

This study investigates the corrosion provoked by the contact between carbon steel and CuAlBe, two dissimilar materials, which provoke a galvanic current from the less noble to the more noble metal. One possible application of the alloy CuAlBe with Shape Memory Affect is to join steel piping without the use of welding. Carbon steel is the most abundantly used material in the field of engineering. It is also widely used in the industry of petroleum production and refining, among other industries, for economic reasons [3, 4]. It is common to find the use of dissimilar materials with carbon steel, such as zinc [5], austenitic steel [6], and aluminum [7].

Methodology

The materials used in this study were grade D carbon steel API 11B from the manufacturer Tenaris Confab, and CuAlBe with Shape Memory Affect which was provided by the Laboratory of Rapid Solidification (LSR) of the Federal University of Paraíba (Brazil).

Experimental Design

Based on the physico-chemical characterizations of the water produced, a 2^{6-2} fractional design with six central points was developed with the following variables: Cl⁻, SO₄⁼, S⁻, HCO₃⁻, ratio of anodic area to cathodic area (1:1, 1:1/2, 1:1/4) and temperature (25, 35 and 45 °C). The anodic dissolution current was calculated through the measurement of the galvanic current. In this way, the affects of the different variables in the response current of the anodic

dissolution may be analized [8]. The statistical analysis was performed using the program Statistics version 5.0. The values of the concentrations utilized in the design of each of the variables are shown in Table 1.

1			
Level	-1	0	+1
Steel Area/CuAlBe	1:1/4	1:1/2	1:1
T°C	25	35	45
[Cl ⁻] ppm	8 000	24 000	40 000
[SO⁴-] ppm	10 000	15 000	20 000
[S ⁼]	10	20	30
[HCO ₃ ⁻]	40 000	50 000	60 000

Table 1. Values of the variables studied that will be utilized in the 2^{6-2} fractional design with six central points.

Galvanic Corrosion

The galvanic contact between carbon steel and the alloy CuAlBe was established by forming a small circuit with them using a G-300 Gamry potentiostat controlled by Gamry Framework software that acts as a Zero Resistance Ammeter. The tests were carried out in three electrode cells with steel as the primary working electrode, substituting CuAlBe for platinum as the secondary working electrode and using a reference electrode of coiled platinum due to the effects of temperature. The experiment was conducted in a time span ranging from 8 to 12 hours, using electrolyte solutions as described in the experimental design. The assays were performed immediately after preparation of the specimens (sanded with metal sanders of the following grits: 400, 800, 1200 and 2000, then washed with distilled water and dried).

Results and discussion

The current of the dissolution of the anode (I_d) can be calculated using the galvanic current (I_g) and the ratio of areas according to the equation (1):

$$I_d = Ig \left(1 + A_c / A_a\right) \tag{1}$$

Thus, the currents were estimated and calculated by knowing the galvanic current (Ig), the latter measured experimentally.

The effect of the area under the intensity of the galvanic current show the anodic dissolution current is directly proportional to the cathodic area and therefore to the reaction of the cathode bias. The ratio is unfavorable to the areas where the surface area of the more noble metal is greater compared to that of the more active metal, in these areas an accelerated rate of corrosion is expected. In the inverse, where the anodic surface area is greater than the cathodic area, the effects on the anodic dissolution current are not as pronounced. The same results observed in this study, however, have been widely discussed in the literature, the difference in this study being the complexity of the environment and the fact that even as such the galvanic coupling theory nevertheless remains proven.

The affect of temperature is potentialized when the anodic area is greater. The increase in temperature of the electrolyte may increase the corrosion of the metal by any of the following means: increasing the conductivity of the electrolyte and the transport of the ions; the acceleration of the chemical reactions in the electrolyte; the acceleration of the electro-chemical

reactions on the surface of the metal; decreasing of the polarization and solubilization of the protective films [1].

Conclusion

The use of the experimental design evaluates the influence of the composition of the electrolyte in the phenomenon of galvanic corrosion found in the oil and gas industry. Within the limits of this study it can be proven that an anodic current of greater density occurs when there is a minimum of anodic area in relation to cathodic area.

References

1 - LEE, K-L J., A mechanistic Modeling of CO_2 Corrosion of Mild Steel in the Presence of H_2S , Doctorate Dissertation presented at the University of Ohio, USA, 2004.

2 - BARGMANN, I.; NEVILLE, A.; HERTZMAN, S.; ARIF, A. B. B. M. Erosion-Corrosion in Oil and Gas – Understanding the Degradation Mechanisms. In: *Proceedings of the European Corrosion Congress*, Freiburg im Breisgau, Germany, 2007.

3 - SANTOS, A. O., Masters Dissertation in Process Engineering, Tiradentes Univerity, Aracaju, SE Brazil December of 2007, Advisors: Paulo Mário Machado Araújo and Eliane Bezerra Cavalcanti.

4 - SOUZA, R. E. A. de, Masters Dissertation in Process Engineering, Tiradentes Univerity, Aracaju, SE Brazil, October of 2007. Advisors: Paulo Mário Machado Araújo and Renan Tavares Figueiredo.

5 - TADA, E.; SUGAWARA, K. and KANEKO, H. "Distribution of pH during galvanic corrosion of a Zn/steel couple" <u>Electrochimica Acta</u>, 49 (7): 1019-1026, 2004.

6 - ABREU, C. M. ; CRISTÓBAL, M. J. , MONTEMOR, M. F. , NÓVOA, X. R. , PENA, G. and Pérez, M. C. "Galvanic coupling between carbon steel and austenitic stainless steel in alkaline media" <u>Electrochimica Acta</u>, <u>47(13-14)</u>: 2271-2279, 2002.

7 - POHLMAN, S. L., General Corrosion, . In: Metals Handbook, v. 13: Corrosion, 9 ed., American Society for Metals, 1987.

8 - BOX, G., E. P.; HUNTER, W. G.; HUNTER, J. S., Statistics for experimenters: An Introduction to Design, Data Analysis and Model Building, New York: Wiley & Sons Inc. pp. 653, 1978.