Evaluation of the structural steel corrosion behaviour, covered with epoxy-type paints, by means of electrochemical DC techniques

Y Salas1, L Guerrero2, R Martinez3, T Chicino3 and C Devia3
1 Universidad Antonio Nariño, Bogotá, Colombia.
2 Universidad Pedagógica y Tecnológica de Colombia, Tunja, Colombia.
3 Universidad Antonio Nariño, Tunja, Colombia.

E-mail: yecsalas@uan.edu.co

Abstract. In this work we have studied the behaviour of the electrochemical corrosion of structural steel AISI SAE 1007 with epoxy coatings, using epoxy-type paints, through techniques such as DC resistance Polarization and Potentio-dynamic tests. In order to determine potential and corrosion rates of these coatings, have been correlated this results with different used electrolytes. For this, coatings were characterized by thickness measurement and continuity measurements. The coatings showed a slight degradation in the testing time, due to defects present in their structure, and the attack by the electrolyte; however, epoxy coating system tends to react with the electrolytes based on their chemical composition.

1. Introduction
Epoxy coatings on steel have opened a number of potential uses such as waterproofing, sealing, bonding, damping, reinforcing and protecting load-bearing structures. The slow degradation and low relative cost of these coatings make them ideal for these purposes [1].

The coating system has properties such as: Low permeability, flexibility, heat resistance, abrasion resistance, resistance to acids and alkalis and other properties that make them viable for coating metal surfaces that want protection against corrosion [2]. Given these properties it is very helpful to use the epoxy system which is the most prominent industrial maintenance for their excellent stiffness, adhesion, alkali resistance, and humidity, temporary or permanent immersion to mineral acids, solvents and moderately good resistance at high temperatures (80 to 90°C) [3].

The purpose of this work is to characterize the corrosion behaviour of epoxy coatings on 1007 steel, using only D.C. electrochemical test (instead of the usual alternating current A.C. method: Electrochemical Impedance Spectroscopy EIS) [4,5], in function of the media (acid, neutral and basic), which give us evidence of coating performance in this different media.

Due to the thickness of the paint the current response was expected it was very small, but the potentiostat used had a very good definition that reached the order of 10⁻¹² Amperes (pA), a fact which was verified in preliminary tests that yielded significant and visible data.

2. Methodology
Structural Steel AISI SAE 1007 specimens were used, supplied by the company SIKA Colombia and previously characterized by spectroscopy arc, with dimensions of 20cm long and 10cm wide and 1.035mm thick, with the respective type epoxy coating systems: A Self-priming Grey epoxy FZ HS, A
epoxyphenolic S400 Ivory, Sika Epoxy 90HS Series A 200 and A 300 series 100HS Epoxy Sika, whose information was compiled manual metal coatings Sika. Electrolytic solutions NaCl, NaOH and H₂SO₄ with concentrations of 3.5, 3.75 and 5% respectively was used, as suggested by the NACE, Standard-TM0169-2000 [6]. These percentages of concentration are determinate to work the electrochemical tests simulate harsh environments, taking into account two aspects, the first is that the pH of the solution does not exceed the reference electrode (Ag/AgCl) so as to avoid this saturation, and the second is the ohmic overpotential having electrolyte solutions especially NaOH and H₂SO₄.

2.1. Experimental design
An experimental matrix design features two factors: Epoxy system with four levels determined by the paint supplied; and type of electrolyte, with three levels acid (H₂SO₄), neutral (NaCl) and basic (NaOH) (See Table 1).

| Epoxy System          | Electrolyte (Media)          | Variables Response |
|-----------------------|------------------------------|--------------------|
| A autoimprimante epóxico gris HS FZ F0898 | Acid: H₂SO₄ 5% Neutral: NaCl 3.5% Basic: NaOH 3.75% | Thickness (mm) |
| A epoxifenolico S400 marfil F0909-14 | Acid: H₂SO₄ 5% Neutral: NaCl 3.5% Basic: NaOH 3.75% | Continuity |
| A sika epoxi 90HS serie 200 F0829 | Acid: H₂SO₄ 5% Neutral: NaCl 3.5% Basic: NaOH 3.75% | βa (mV/dec) βc (mV/dec) CR (mm/yr) |
| A sika epoxi 100HS serie 300 F0994 | Acid: H₂SO₄ 5% Neutral: NaCl 3.5% Basic: NaOH 3.75% | LPR (Ω·cm²) |

2.2. Materials and methods
For the electrochemical test was used the electrolytes mentioned in the experimental matrix, a scan rate of 2mV/s, an exposed area of 9.62cm² with a sweep from -250mV to +250mV with respect to Ecorr [7]. The SAE 1007 steel was previously characterized by means of arc spectroscopy and painted in the sika’s plant in Tocancipa, Colombia. The reference electrode used was Ag/AgCl.

2.2.1 Electrochemical methods. Potentio-dynamic curves performed were analysed by means of Tafel approximation and in the LPR test values of linear polarization resistance were deducted.

2.2.2. Continuity tester. For continuous measurements epoxy coatings systems of all samples the same procedure was performed considering the suggestions described ASTM D 5162-A [8], both for the preparation of the specimens, as for the measurement and use Meter Compact equipment continuity PCWİ™.

2.2.3. Electrochemical equipment. The Gamry G-750 Potentiostan-Galvanostats, an electrode Ag/AgCl and a flat electrochemical cell was used for generate the potentio-dynamics and LPR curves and is located in the Materials Lab of the Universidad Antonio Nariño, Tunja, Colombia.

2.2.4. Magnetic thickness gauge. Epoxy coating thickness can be measured on magnetic 1020 steel surfaces using a digital Elcometer™ coating thickness gauge. The principle of electromagnetic induction is used for non-magnetic coatings, on magnetic substrates such as SAE 1007 steel.
3. Results
The obtained results are reported in the Figure 1 and in the Table 2. In the potentiodynamics graphics (Figure 1), the x axis is the base 10 logarithm of current (Amperes) and the y axis is the potential E in volts respect to E reference.

![Figure 1. Curves for the three types of electrolyte with the four coating systems.](image)

| Table 2. Resume for experimental data obtained. |
|-----------------------------------------------|
| Epoxy system | NaCl 3,5% electrolyte | NaOH 3,75% electrolyte | H₂SO₄ 5% electrolyte |
|--------------|------------------------|------------------------|----------------------|
|              | CR mm/y | LPR Ω·cm² | Thick mm | CR mm/y | LPR Ω·cm² | Thick mm | CR mm/y | LPR Ω·cm² | Thick mm |
| A autoimprim | 8,41E-07 | 1,92E+09 | 0,34 | 8,86E-07 | 9,62E+08 | 0,45 | 1,22E-07 | 1,92E+09 | 0,31 |
| epoxic gris |             |             |       |             |             |       |             |             |       |
| HS FZ        |             |             |       |             |             |       |             |             |       |
| A epoxifenolico S400 marfil | 2,05E-06 | 5,77E+08 | 0,61 | 1,62E-07 | 1,92E+09 | 0,37 | - | - | - |
| A sika epoxi 90HS serie 200 | 3,26E-08 | 9,62E+09 | 0,3 | 5,53E-06 | 2,89E+08 | 0,3 | 3,84E-07 | 9,62E+08 | 0,3 |
| A sika epoxi 100HS serie 300 | 3,25E-08 | 9,62E+09 | 0,95 | 7,61E-08 | 4,81E+09 | 0,57 | 1,78E-07 | 3,85E+09 | 0,43 |

4. Discussion
In the Figure 2 it is compared the corrosion rate for the four types of paint systems. It is noteworthy that the system epoxyphenolic saturate the equipment when subjected to H₂SO₄ electrolyte. The epoxy 90HS system present a notable corrosion rate for a basic media, the same way that the epoxyphenolic with neutral medium. The epoxy 100HS system had the best performance to maintain their corrosion rates around 10⁻⁷mm/y for all electrolytes.

For all the systems the polarization resistance is practically the same values remaining at around tenths of Giga Ohms per square centimeter.
5. Conclusions

The Electrochemical Techniques D.C. are a very good method to determine the quality of epoxy coatings systems and application media, based on their respective corrosion and graphical analysis.

The coating system A epoxyphenolic S400 Ivory did not react to the acid environment by having polyamide in their chemical composition.

Based on the results obtained in the study and evaluation of epoxy systems with respect to pH range, i.e. the means in which we evaluated, we can say that more stable system and better performance in the three media both rich chlorides such as alkali and acid was sika epoxy system A 100HS Series 300, which does not mean that the other systems are not as efficient as this, since the lineal polarization resistance as was observed were in the order of $G \, \Omega \, \text{cm}^2$.

Coating systems possessing polyaminoamides have better performance than polifenilamida systems present in their chemical structures.

References

[1] Carbonelli C 2010 Pinturas y recubrimientos introduccion a su tecnologia (Madrid: Diaz Santos)
[2] Gupta A and Dev A 2008 J Plastic Industry 32 1
[3] Lee H and Neville K 1967 Industrial & Engineering Chemistry 59-9 16
[4] Haynes G S 1985 Laboratory corrosion tests and standards a symposium by ASTM committee G-1 on corrosion of metals (Bal Harbour: ASTM International)
[5] Diaz F 2001 Estudio de la corrosion atmosferica del cinc y el acero galvanizado (Santa Cruz de Tenerife: Universidad la Laguna)
[6] Guzman A and Ocampo C L 2011 Evaluacion de la resistencia a la corrosion del sistema primer epoxico rico en Zinc/acadabado polisiloxano por medio de espectroscopia de impedancia electroquimica (Medellin: Universidad Nacional de Colombia)
[7] ASTM-G5 1994 Standard reference test method for making potentiostatic and potentiodynamics anodic polarization measurements (West Conshohocken: ASTM International)
[8] ASTM-G5 2008 Standard practice for discontinuity (Holiday) testing of nonconductive protective coat (West Conshohocken: ASTM International)