CORROSION OF MATERIALS FROM A TEACHING POINT OF VIEW

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Abstract

In the present study, a numerical methodology based on the finite element analysis (FEA) is proposed to facilitate learning about technical concepts related to corrosion phenomena, from a teaching point of view. FEA is oriented to reinforce theoretical and practical lessons commonly introduced in university teaching. Impressions of students, about this teaching methodology, is also shared in this work.

Keywords: Teaching, Corrosion, Material Science.

1 INTRODUCTION

Corrosion can be defined as deterioration of metallic components due to electrochemical reactions with the metal and its environment [1]. In the fight against corrosion, research and new technological developments are oriented towards minimizing the effects of this phenomenon in order to delay its 'unavoidable appearance'.

Currently, the most common lines of research in this area focus on the knowledge of corrosion mechanisms and material protection systems. At the teaching level, in Engineering and particularly, within Electrochismtry area, theoretical knowledge about corrosion is well-documented but, is it correctly transmitted to the new generations of students taking into account the important economic losses caused by corrosion in the world of industry?

Corrosion is an interdisciplinary and complex field in which physical, chemical and mathematical knowledge is essential to understand materials behavior in aggressive environments. Due to this fact, it is important to educate students who are interested in Science from an earlier age. In this context, some experiences (in secondary education) have been shared [2,3].

Definitely, at the teaching level, it is important to make students aware of the important problem that corrosion generates at the industrial level, since corrosion damage causes large economic losses, which are equivalent to 3.4% of the global GDP [4]. Are we aware of this problem?. At this point, it is essential to strengthen theoretical knowledge of corrosion through electrochemical laboratory practice, combined with the use of commercial simulation programmes, which can contribute to a better understanding of corrosion damage to try to understand and 'mitigate' its appearance.

This work presents a teaching methodology, combining theoretical lessons, practical lessons and numerical simulations, in order to introduce and understand some of the corrosion aspects, from a teaching point of view.

2 METHODOLOGY

Figure 1 displays the combined methodology (teaching in the classroom, teaching in the laboratory and numerical simulations) in this study to introduce 'galvanic corrosion' concept. This working methodology was implemented in the Advanced Corrosion Seminar (four hours duration) within the Master's Degree in Integrity and Durability of Materials, Components and Structures. Eight students, from several Universities, participated in the Seminar.

Initially, galvanic corrosion concept was introduced from a theoretical point of view. As an example, galvanic couple to introduce 'galvanic corrosion' concept was explained when a magnesium alloy is in contact with a carbon steel in salt water. In this case, magnesium (-1.5V vs. SCE) with a lower free potential in a galvanic couple becomes more active and corrodes preferentially in contact with steel (-0.6V vs. SCE), Figure 1a.

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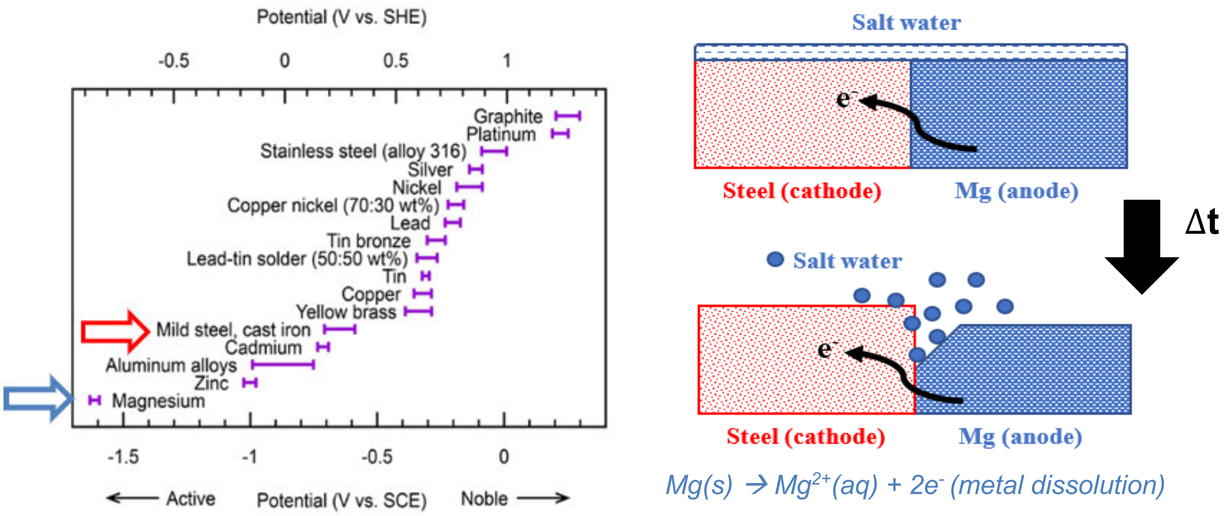
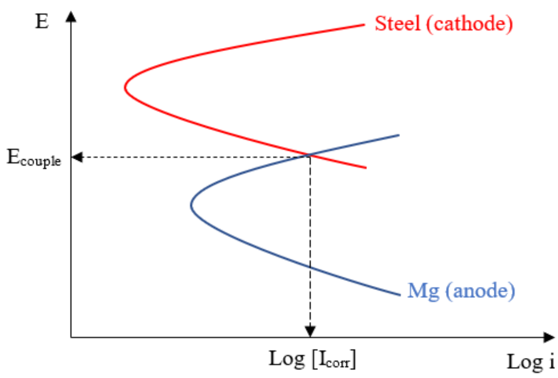
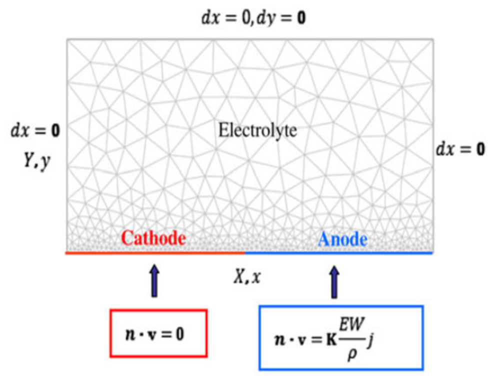


(a) Teaching in the classroom



(b) Teaching in the laboratory



(c) FEA in COMSOL Multiphysics

Figure 1. Theoretical, practical and numerical aspects to introduce corrosion

In a second step, polarization experiments were introduced at the laboratory to understand experimentally, the theoretical explanation previously given in the classroom about the mixed potential theory and galvanic couples. We consider it is very important to explain students the existing experimental methodologies and available devices to analyze corrosion at the laboratory scale. Polarization experiments were performed in the laboratory by means of a flat cell (Figure 2) and an Ivium Vertex C potentiostat. Test conditions are described in Table 1.

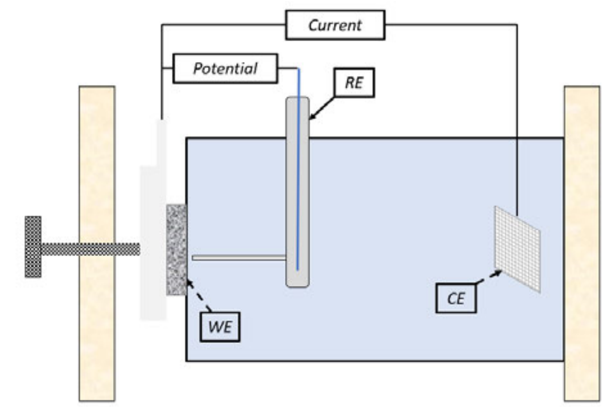


Figure 2. Experimental set-up. WE: working electrode. RE: reference electrode and CE: Counter electrode (Pt)

Table 1. Test conditions

E_{start} (V) vs. OCP	-0.7
E_{end} (V) vs. OCP	+0.7
Scan rate (V/h)	0.6
Solution	Salt water
Temperature (ºC)	22

Finally, a finite element analysis (FEA) was also carried out to a better understanding of the galvanic couple Mg/steel (Figure 3). Simulations were performed by means of COMSOL Multiphysics software. For more data, the employed model is better described in [5].

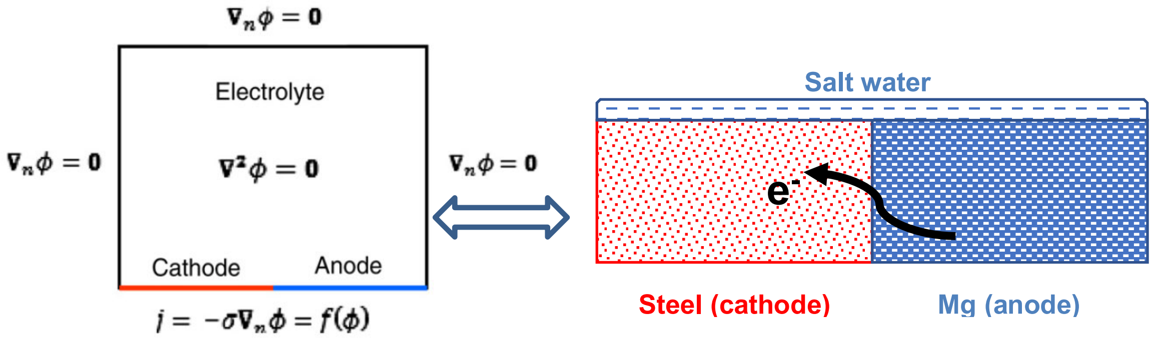


Figure 3. Numerical model of the Mg/steel couple

The use of simulation softwares, as COMSOL Multiphysics, permit students predict what can happen when dissimilar metals are in contact to form a galvanic couple. As discussed later, this fact seems to reinforce the theoretical and practical points.

3 RESULTS

Taking into account the proposed methodology, polarization experimental results are shown in Figure 4. The experimental proposal allowed students understand some of the existing experimental methodologies to analyze corrosion behavior of metals at the laboratory scale.

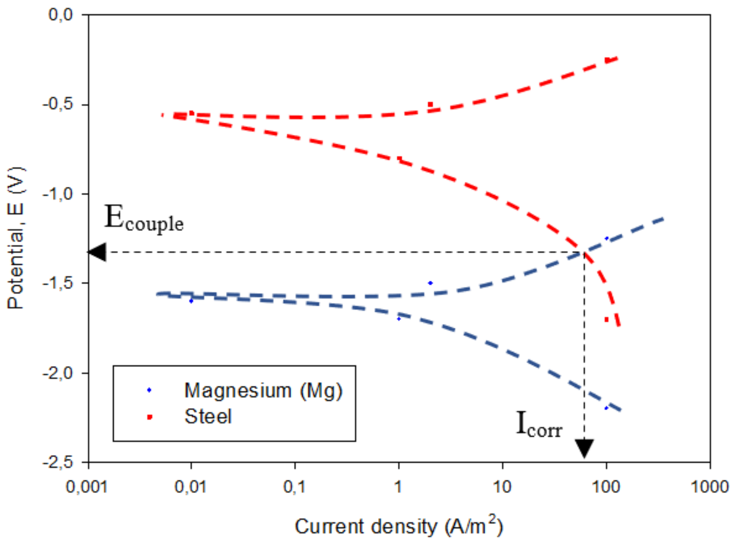


Figure 4. Experimental results. Polarization experiments

From this results, students understood satisfactorily the 'polarization concept' applied to a Mg/steel galvanic couple. Accordingly, students were able to select the galvanic couple potential (E_{couple}) and the corrosion current density (I_{corr}). These values are summarized in Table 2.

Table 2. Results obtained from polarization experiments (Figure 4)

Galvanic couple	*E_{couple} (V)*	*I_{corr} (A/m^2)*
Mg vs. steel	-1.3	90

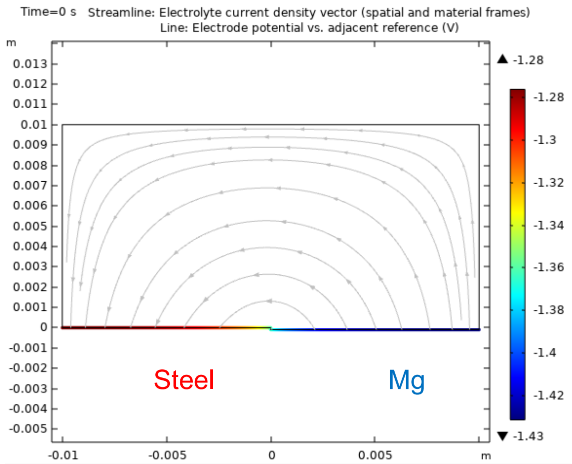
As mentioned above, experimental results were numerically simulated in order to reinforce theoretical aspects related to galvanic couples that can promote corrosion phenomena. Figure 5 displays the potential gradient and current density distribution in the salt solution. The electrode current density is highest at the contact point Mg/steel (Figure 5b). Accordingly, the metal dissolution was also maximum at this point ($Mg \rightarrow Mg^{2+} + 2e^-$). This fact allowed students establish a clear relationship with theoretical concepts previously introduced in Figure 1a where potential difference, between Mg (very active) and steel (less active compared to Mg), promotes Mg dissolution in the galvanic couple.

Some of results obtained from the numerical simulations (FEA) are displayed in Table 3.

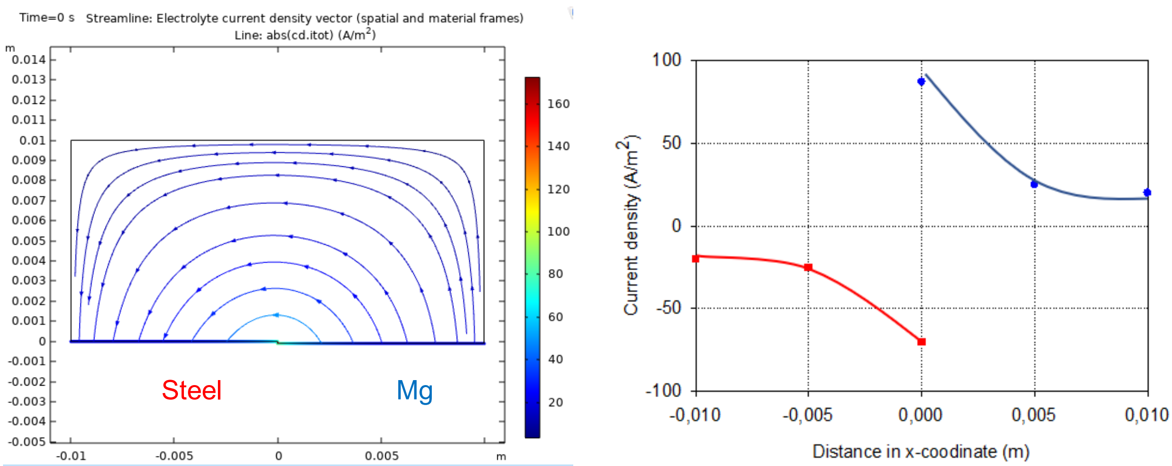
Table 3. Results obtained from the FEA

Galvanic couple	***E_{couple} (V)***	***I_{corr} (A/m^2)***
Mg vs. steel	-1.36	85

The employ of these numerical simulations was notably appreciated by students as they could correlate the experimental and numerical results. It can be seen that the electric potential varies from -1.28 V over the cathodic region to -1.42 V over the anodic region (Mg) in Figure 5a. It should be noted that the potential of the same galvanic couple was estimated to be -1.3 V using the mixed potential theory, as previously evidenced in Figure 4.



(a)



(b)

Figure 5. Numerical results. (a) Potential gradient. (b) Current density distribution (left) and current peak density (right) over the galvanic couple

Additionally, it can be seen that the current density peak over the anodic region predicted by the model is ≈85 A/m^2 (Figure 5b). It should be noted that the galvanic current density estimated from the mixed potential theory is about 90 A/m^2 (Table 2 and Figure 4). Thus, the current density of the galvanic couple estimated using the mixed potential theory is in reasonable agreement with the numerical predictions. After the corresponding explanations, the eight students were able to relate these concepts satisfactorily.

4 CONCLUSIONS

The combined methodology of theoretical explanations in the classroom combined with practical lessons at the laboratory and numerical simulations carried out by COMSOL Multiphysics software, has allowed students to understand well 'galvanic corrosion' concept. Feelings, experimented by students after the described methodology during the Advanced Corrosion Seminar, are given in Table 4. The proposed methodology has been graded as 'very good' by most students.

Table 4. Student's feelings about the proposed methodology to understand 'galvanic corrosion' concept

Student	***Bad***	***Good***	***Very good***
1		X	
2			X
3			X
4		X	
5			X
6			X
7			X
8			X

It is important to say that some of them had already taken contact with corrosion concepts in their stage as students of Mechanical Engineering and Materials Engineering. At the beginning of the course and prior to introduce corrosion through the proposed methodology, some of these students had defined corrosion as *'boring and really difficult to understand'*. From the students point of view, this awareness was associated to the lack of laboratory experiments. During the Corrosion Seminar, this feeling seemed to change when theoretical aspects (theory lessons) were mainly reinforced with experimental corrosion techniques at the laboratory. Additionally, simulations conducted by means of COMSOL Multiphysics software allowed to enhance theoretical explanations that served as the basis for correlating the experimental and numerical results.

After this brief experience, we may ask ourselves again: *'from a teaching point of view, are corrosion concepts correctly transmitted to students?'*. We have concluded that the eight students have given much importance to experimental work performed at the laboratory and they have understood the 'galvanic corrosion' concept in a better way, when experimental and numerical techniques are combined with theoretical lessons.

Lastly, regarding the question previously done in the introduction chapter '*corrosion damage causes large economic losses, which are equivalent to 3.4% of the global GDP. Are we aware of this problem*?. At the beginning of the Corrosion Seminar, only two students were aware of this important data. After the Seminar, student's motivation to deal with corrosion-related issues seemed to be reinforced.

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REFERENCES

[1] Peral LB, Zafra A, Bagherifard S, Guagliano M, Fernández-Pariente I. Effect of warm shot peening treatments on surface properties and corrosion behavior of AZ31 magnesium alloy. Surf Coat Technol 2020;401:126285. https://doi.org/10.1016/j.surfcoat.2020.126285.

[2] Franco-Mariscal AJ. Scientific competences in teaching and learning through research. A case study about the corrosion of metals in secondary education. Enseñanza de Las Ciencias 2015;33:231–52. https://doi.org/10.5565/rev/ensciencias.1645.

[3] Lazo Santibañez L, Vidal Fuentes J, Vera Aravena R. La enseñanza de los conceptos de oxidación y de reducción contextualizados en el estudio de la corrosión. Revista Eureka Sobre Enseñanza y Divulgación de Las Ciencias 2013;10:110–9. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2013.v10.i1.08.

[4] NACE International (2016)

[5] Deshpande KB. Validated numerical modelling of galvanic corrosion for couples: Magnesium alloy (AE44)-mild steel and AE44-aluminium alloy (AA6063) in brine solution. Corros Sci 2010;52:3514–22. https://doi.org/10.1016/j.corsci.2010.06.031.