

## Effect of Galvanic Coupling Between Stainless Steel and Carbon Steel on the Rupture of Passive Film

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The galvanic corrosion can appear on heterogeneous coupling such as the contact of stainless steel and carbon steel. Carbon steel is then anodic compared to stainless steel. We studied the influence of surface ratio (stainless steel/carbon steel) on galvanic corrosion in a chloride solution. The potentiodynamic polarization and morphological observations in scanning electronic microscopy have been used for this study. The conclusions of present study can be summarized as follows: (a) the corrosion potential and rate of combined materials are between those of materials taken only. The potential of stainless steel is higher than that of carbon steel (b) the micrographics of the working electrode reveal that the generated phenomenon is a galvanic phenomenon of corrosion.

**Key Words:** Corrosion, Stainless steel, Carbon steel, Protection.

### INTRODUCTION

Corrosion is a daily problem, which proves to be of capital importance. This is due to two reasons *i.e.*, at the costs which the oxidation of materials involves (that it is on the level of the losses of energies or the means implemented in order to minimize this phenomenon on the level of the worn parts to replace), and with the disastrous consequences which can have corrosion on the properties of a material and thus on safety (for example in oil industry)<sup>1</sup>.

Corrosion generally intervenes on materials constituting the equipment, mainly, carbon steels. The environments are varied but often very corrosive and the use of noble metals (stainless steels) is not economically possible<sup>2</sup>.

The aim of this work is to study corrosion behaviour of the assembly of two varieties of steels (carbon steel and stainless steel 13 % Cr) in a chloride containing solution<sup>3-8</sup>. They constitute the base of many industrial materials.

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The control of galvanic corrosion passes by the comprehension of the mechanisms brought into play and by the knowledge of the various parameters, which act on: (i) the nature of the contact between metals, (ii) importance of surfaces and (iii) the nobility of the metal elements presents. This nobility being able to vary with the concentration, passivation, aeration.

This paper deals with (i) the consideration of the consequences of various ratios of surface stainless steel/carbon steel: 100/0, 50/50 and 0/100 and various times of immersion (from 0 to 6 months) on the physico-chemical properties of these materials particular in galvanic corrosion resistance, (ii) the plot of the curves of polarization in an acid chloride containing solution which approaches the media in which these materials are used and (iii) the determination of the electrochemical characteristics of these materials to envisage the combined compounds up to what point cathodically are likely to protect the stainless steel.

### EXPERIMENTAL

The materials studied in present work are carbon steel and the stainless steel (Fe-13 % Cr) coming from tubing. Their chemical compositions are given in Table-1.

TABLE-1  
CHEMICAL ANALYSIS OF THE TWO STEELS

Elements (%)	C	Cr	Mn	Si	S	P	Ni	Mo	Fe
Stainless steel	0.20	12.90	0.79	0.72	0.007	0.004	0.08	0.015	Balance
Carbon steel	0.22	0.03	1.51	0.31	0.009	0.013	0.01	0.040	Balance

In order to reveal the structure of samples, we have proceeded to chemical attack in a reagent Nital for carbon steel or Vilella for the stainless steel. The observation in optical microscopy of chemically attacked surface revealed the martensitic structure for the two materials.

In present studies two types of work electrodes have been used for this study: stainless steel 13% Cr (A), carbon steel (B), and combined steel (C) which was prepared by combination of the precedents according to ratios of surface stainless steel/carbon steel: 50/50 % ( $C_{50}$ ). The combined electrode is illustrated in Fig. 1.

**Immersion tests:** After polishing, the electrodes were emerged in Erlenmeyer container, 100 mL of an electrolytic solution of 35 g/L of NaCl at pH 3, for various times of immersion (from 1 to 6 months).

Before any study, the surface of the work electrode is cleaned with ethanol in order to clean the surface of the products of corrosion, which was formed during the immersion.

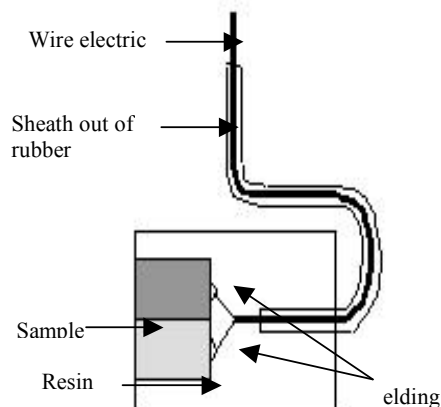


Fig. 1. Diagram of the transverse section of the combined electrode

**Electrochemical tests:** The electrochemical measurements were conventional three-electrode system. Stainless steel, carbon steel and combined materials are used as a work electrode in electrochemical tests before and after immersion. The auxiliary electrode of spectra graphite symmetrically disposed and ESC as reference electrode. The cell is connected to potentiostat/galvanostat 273 A EG&G using an electrometer.

All the electrochemical tests were carried out under identical conditions. It is aerated solution of 35 g/L NaCl at pH 3 (aggressive electrolyte). For electrochemical tests, a potentiodynamic polarization technique is used with a scanning rate of 0.16 mV/s.

## RESULTS AND DISCUSSION

**Tests of immersion:** After immersion, the carbon steel had rough surface and suffered from corrosion, contrary to stainless steel. In the combined steel ( $C_{50}$ ), only the carbon steel has been attacked and the stainless steel not suffered.

**Electrochemical tests:** The results obtained by potentiodynamic technique to study the process of corrosion of the worked electrodes in the solution are given in Table-2. The curves obtained are illustrated in Fig. 2.

It is noted that the value of potential, in the case of combined steels is included between the values taken by carbon steel and the stainless steel for times from 2 to 6 months of immersion. The value of corrosion potential of combined steels approaches to the value of corrosion potential of carbon steel.

Generally, before and after immersion (from 1 to 6 months), combined steels have a compartment close to that of carbon steel. The curves of potentiodynamic polarization relating to times of immersion higher than 1 month are intermediate between those of the stainless steel and carbon steel.

TABLE-2  
ELECTROCHEMICALS CHARACTERISTICS OBTAINED BY  
POTENTIODYNAMICS POLARIZATION FOR DIFFERENTS RATIO  
OF SURFACE STAINLESS STEEL/CARBON STEEL

Corrosion parameters	Months						
	B: Carbon steel						
	0	1	2	3	4	5	6
$V_{\text{corr}}$ (mm/year)	1.276	0.477	0.133	0.166	0.142	0.251	0.188
$E_{\text{corr}}$ (mV/ECS)	-717.8	-616.6	-656.4	-670.7	-674.2	-685.5	-687.6
$I_{\text{corr}}$ ( $\mu\text{A cm}^2$ )	244.70	91.60	29.05	31.96	21.81	38.64	36.12
$C_{50}$ : 50/50 %							
$V_{\text{corr}}$ (mm/year)	0.242	0.143	0.195	0.200	0.207	0.151	0.245
$E_{\text{corr}}$ (mV/ECS)	-639.8	-611.1	-602.5	-636.0	-651.9	-659.4	-668.3
$I_{\text{corr}}$ ( $\mu\text{A cm}^2$ )	46.46	27.47	37.73	74.70	39.07	28.97	47.07
A: Stainless steel							
$V_{\text{corr}}$ (mm/year)	0.144	0.001	0.008	0.029	0.005	0.01	0.009
$E_{\text{corr}}$ (mV/ECS)	-549.1	-439.3	-358.3	-495.4	-498.1	-520.2	-509.6
$I_{\text{corr}}$ ( $\mu\text{A cm}^2$ )	30.21	0.23	0.164	4.56	1.04	6.40	1.90

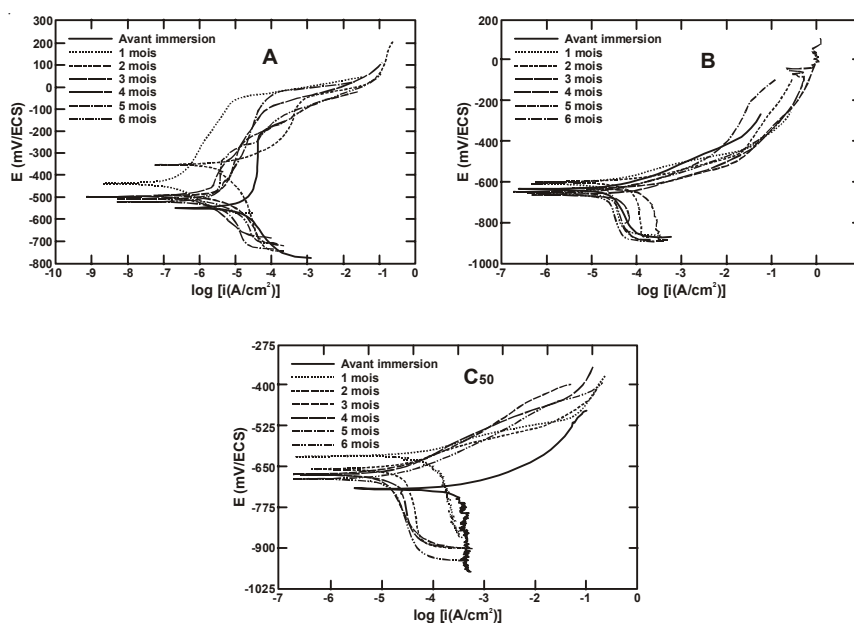


Fig. 2. Curves of potentiodynamic polarization of Stainless steel (A), carbon steel (B) and combined material (C<sub>50</sub>) at various times of immersion

The beginning state of corrosion during the first month of immersion has been observed. It is also noted that the value of potential, in the case of combined steels is included between the values taken by carbon steel and the stainless steel for 2 to 6 months of immersion.

Generally, before and after immersion (from 1 to 6 months), it is noticed that combined steels have a behaviour close to that of carbon steel.

The polarization curves of the stainless steel indicates the existence of a stage of passivity due to the passive character of chromium<sup>9</sup> before and after immersion (Fig. 2A). It is less significant to 2 and 3 months of immersion. For all times of immersion, one notes that carbon and combined steels corroded more quickly than the stainless steel<sup>10</sup>.

For the stainless steel after 6 months of immersion, a mode of dissolution is noted around -300 mV/ECS in the stage of passivity, resulting in an increase in the current (probably due to the rupture of passive film).

In all cases, the stainless steel (A) corrodes less than other steels<sup>10</sup> and the rate of corrosion is lower. It decreases according to the time of immersion. It resulted from that the variation of the rate of corrosion relating to the stainless steel is for the longest times of immersion below that of other steels. This seems to indicate that the increase in the time of immersion leads layers formed on the surface of the stainless steel (A), more protective character<sup>11,12</sup>. This protection is marked during the first month of immersion.

**Electronic scan microscopy:** The observation of surfaces of the electrode used under the scanning electron microscope was only carried out after 6 months of immersion. The micrographics are represented in Table-3.

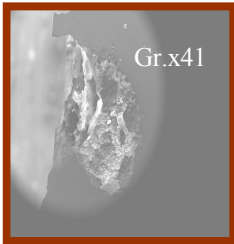
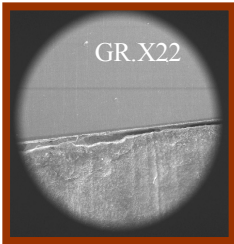
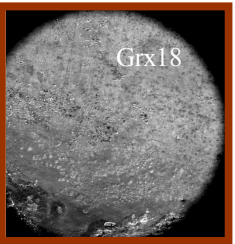
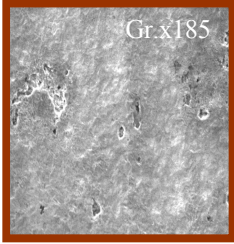
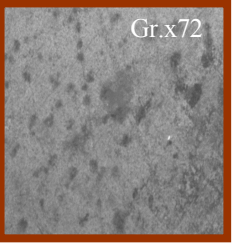
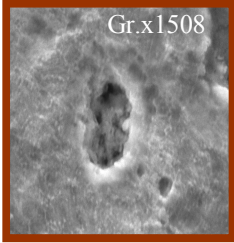
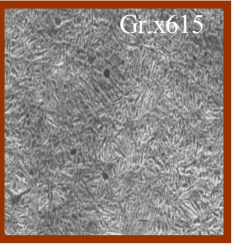
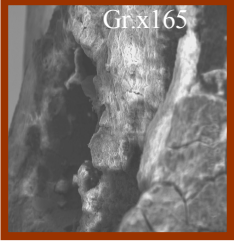
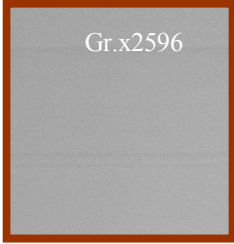
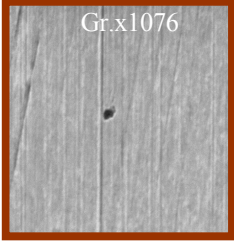
The surfaces examined by SEM have not an uniform aspect (Table-3). On the carbon steel, in addition to the phenomenon of generalized corrosion, we notice the presence of pitting. This phenomenon was observed by Evans<sup>13</sup> and was confirmed by Wranglen and Shreir<sup>14,15</sup>. They deduced that the autocatalytic process is a function of the increase in the concentration of Cl<sup>-</sup> around the pitting.

In the case of the stainless steel, it is observed pits of various dimensions, however, in the case of combined steels, corrosion is sufficiently marked to make an interesting comparison between carbon steel and the stainless steel. It is clear that carbon steel is preferentially attacked compared to the stainless steel. On the stainless steel, corrosion seems less aggressive and more localized in certain points of surface where the pits appear.

### Conclusion

In this work, the behaviour of the coupled steel stainless to the carbon steel, placed in an aggressive environment has been studied. This environment is consisted of an acid solution of 35 g/L NaCl at pH = 3. The conventional electrochemical techniques: the curves of polarization have been used. The behaviour of the steels combined in ratios of surface: 50/50 (C<sub>50</sub>) with that of carbon steel (B) and the stainless steel (A) was compared and the following essential points were highlighted:

TABLE-3  
MORPHOLOGY OF THE SURFACE OF THE ELECTRODES  
AFTER 6 MONTHS OF IMMERSION

	A	C <sub>50</sub>	B
Overall picture			
Carbon steel			
			
Stainless steel			
			

The layout of the polarization curves enabled us to know the electrochemical properties of the assembly level vs. times of immersion (from 0 to 6 months).

The values of the potentials of corrosion of combined steels are between two steels taken alone (stainless steel and carbon steel).

Generally, the behaviour of the electrode C<sub>50</sub> is closer to carbon steel than that of the stainless steel.

On the one hand, the morphology of the surface of the stainless steel and carbon steel after six months of immersion, observed with the SEM, showed pits of various sizes. On the other hand, for combined material C<sub>50</sub>, we did not observe pits on the stainless steel.

In a particular way, the behaviour of the electrode C<sub>50</sub> after 6 months of immersion, indicates that carbon steel dissolves preferentially in contact with the stainless steel (carbon steel is anodic compared to the stainless steel and it is preferentially attacked).

The protection of the stainless steel by assembly becomes more favourable when the surface of carbon steel increases. Thus, carbon steel protects the stainless steel.

## REFERENCES

1. D. Landolt, *Corrosion et Chimie de Surface des Matériaux*, Vol. 12, Presses Polytechniques et Universitaires Romandes (1993).
2. P. S. Jackman and L. M. Smith, *The European Federation of Corrosion Publications N° 26*, IOM Communications, UK (1999).
3. C.M. Abreu, M.J. Cristobal, M.F. Montemor, X.R. Novoa, G. Pena and M.C. Pérez, *Electrochim. Acta*, **47**, 2271 (2002).
4. L. Bertolini, M. Gastaldi, M.P. Pedefferri, P. Pedefferri and T. Pastore, Proc. Int. Conf., On Corrosion and Rehabilitation of Reinforced Concrete Structures, Orlando, FL, USA, 7-11 December (1998).
5. S.M. Shushan, E.A. Charles and J. Congleton, *Corr. Sci.*, **38**, 673 (1996).
6. R.D. Kane, S.M. Wilhem, T. Yoshida, S. Matsui and T. Iwase, Analysis of Bimetallic Pipe for Sour Services, Presented at the NACE Symposium on Environmental Effects on Advanced Materials (ADV MAT/91), San Diego, CA (1991).
7. W.C. Chen and C.W. Peterson, *SPE Produc. Eng.*, **7**, 375 (1992).
8. Y. Gourbeyre, L. Rytirova, J. Galland, C. Dagbert and L. Hyspecka, Study and Control of Corrosion in the Perspective of Sustainable Development of Urban Distribution Grids, 1st International Conference of Proceedings, Constanta, Romania, 6-8 June, p. 84 (2002).
9. S. El-Hajjaji, L. Aries, J.P. Audouard and F. Dabosi, *Corr. Sci.*, **37**, 927 (1995).
10. J.H. Qiu, *Surface Interface Anal.*, **33**, 830 (2002).
11. I. Olefjord and B.O. Elfstrom, *Corrosion*, **38**, 46 (1982).
12. W.R. Cieslak and D.J. Duquette, *Corrosion*, **40**, 545 (1984).
13. U.R. Evans, *The Corrosion and Oxidation of Metals*, Edward Arnolds, London, p. 127 (1961).
14. G. Wranglen, *An Introduction to Corrosion and Protection of Metals*, Chapman and Hall, London, p. 24 (1985).
15. L. Shreir, in eds.: L.L. Shreir, K.A. Jannan and G.T. Burstein, *Localized Corrosion, In Corrosion*, Butterworth-Heinemann, Oxford, p. 181 (1994).

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