Comparative Study on The Corrosion Behavior of High Strength Pipe Steel After Thermal and Thermomechanical Treatments

D. Berdjane¹, B. Maalem¹, O. Ghelloudj¹, A. Gharbi¹, L. Tairi¹, and S. Djemili¹
¹Research Center in Industrial Technologies (CRTI), P.O. Box 64 Cheraga 16014 Algiers, Algeria

E-mail: berdjamel@yahoo.fr, d.berdjane@crti.dz

Abstract. The corrosion behaviour of X80 steel samples rolled and other quenched-tempered in 3.5% NaCl have been studied. Optical microscopy, scanning electron microscopy, potentiodynamic polarization tests and electrochemical impedance measurements are the techniques used to characterize the samples. The results show that the tempered steel has a low corrosion current density compared to the rolled steel. The impedance measurements show the presence of a single capacitive loop attributed to the load transfer phenomenon.

1. Introduction

The long-distance transportation of oil and gas by pipeline requires the use of reliable materials that offer a better mechanical strength, resilience and corrosion resistance. The durability of structures depends on their behavior in the face of the climatic and environmental conditions that exist in the medium in which they are constructed [1-4]. Our material is a micro alloyed steel with V-Nb-Ti grade X80, generally used for the manufacturing of pipes [5]. These pipes are interred by different media and are exposed to corrosion to varying degrees depending on the nature of the environment [6-8]. Several techniques have been used to improve the corrosion resistance of these steels. Generally, heat treatments are utilized to give a higher mechanical strength with a relatively acceptable corrosion resistance [9-11]. The objective of this work is to study the corrosion behavior of rolled X80 steel and other quenched and tempered steels.

2. Materials and methods

The study material is a high-strength X80 steel used for pipeline construction. The chemical composition is given in Table 1.

| Sample code | C     | Mn   | Si   | P     | S     | V    | Nb  | Ti  | Cu  | Mo  |
|-------------|-------|------|------|-------|-------|------|-----|-----|-----|-----|
| X80         | 0.08  | 1.75 | 0.41 | 0.017 | 0.007 | 0.002 | 0.073 | 0.015 | 0.024 | 0.009 |
The samples were quenched at 1100°C and tempered at 550°C for 90 minutes. The mechanical characteristics of X80 steel before and after thermal treatment are shown in Table 2.

### Table 2. Mechanical Properties of X80 rolled and tempered steels.

| Designation          | Re (MPa) | Rm (MPa) | A (%) | Re/Rm | Hv Hardness |
|----------------------|----------|----------|-------|-------|-------------|
| X80 Rolled steel     | 577      | 685      | 33    | 0.84  | 233         |
| X80 Tempered steel   | 566      | 671      | 35    | 0.84  | 226         |

The metallographic study was carried out using a Nikon type optical microscope and a Zeiss type scanning electron microscope on mechanically polished samples and chemically etched with 4% Nital. The electrochemical behavior of the rolled and treated X80 steel were studied in after one-hour immersion in 3.5% NaCl, using a Metrohm Autolab potentiostat-galvanostat piloted by a computer. A three-electrode electrochemical cell, a platinum electrode, a saturated calomel reference electrode and the third working electrode, which represents the X80 steel, were used. The potentiodynamic polarization tests were performed in the potential range (-1 to 0.6) V/SCE with a speed of 1mV/S. Electrical impedance measurements were performed in a frequency range from 100 kHz to 10 mHz, with a signal amplitude of 10 mV [12].

3. Results

3.1. Metallographic examinations

The structures of as-received rolled X80 steel revealed a fine ferritic-pearlitic structure with homogeneity of grain size and shape (Figure.1).
The observation of the structure by the optical and SEM microscope after the heat treatment proves that it type fine ferrite and pearlite. The percentages of phases and grain size are shown in Table 3.

| Steel quality          | Structural Phases                  | Grain size (µm) |
|------------------------|------------------------------------|-----------------|
| X80 Rolled steel       | F%77+P%23 (Slow pearlitic transformation). | 10.7            |
| X80 Tempered Steel     | F%79+P%11 (Pearlite in the form of troostite, faster transformation). | 11.1            |

The results in Table 3 show that the tempering treatment results in a higher percentage of pearlite (troostite) with a small grain size that increases the hardness (table 2). Troostite is a particular form of the pearlite phase formed during the transformation from austenite to pearlite under faster cooling after martensitic transformation.

3.2. Corrosion behavior
The polarization curves of the X80 steel in the rolled and processed state are shown in Figure 2. Both curves show the two domains cathodic and anodic. We note the presence of a passivation domain between (-0.2 to 0.4) V/SCE for both curves. This domain is due to the formation of oxides on the surface of the material [13-15]. The parameters deduced from the polarization curves are summarized in Table 4. According to the results in Table 4, it can be seen that the tempering treatment reduces the corrosion current density (Icorr) of X80 steel to the value 7.5423.10^-8.

![Figure 2. Polarization curves of rolled and tempered X80 steels.](image-url)

| Steel               | Ecorr (V) | Icorr (A/cm²) | Corrosion rate (mm/year) | Rp (Ω)   |
|---------------------|-----------|---------------|--------------------------|----------|
| X80 Rolled steel    | -0.52847  | 1.12.10^-7    | 0,0012                   | 67042    |
| X80 Tempered steel  | -0.52415  | 7.54.10^-8    | 0,0009                   | 63981    |
Figure 3 shows the Nyquist diagram of rolled and tempered X80 steel at room temperature of 25°C. Both impedance diagrams show a single capacitive loop attributed to the charge transfer phenomenon [16]. The tempering treatment caused a decrease in the size of the capacitive loop. The transfer resistance (Rct) reflects this (Table 5).

![Figure 3. Impedance diagrams of (a) rolled X80 steel (b) tempered X80 steel.](image)

The modeling of the metal/electrolyte interface has been proposed using an electrical circuit equivalent to the figure 4. The circuit consists of an electrolyte resistor (Re) in series with a system formed by: constant phase element (CPE) in parallel with the charge transfer resistance (Rct).

![Figure 4. Equivalent circuit used.](image)

Based on the results of the parametric (Table 5) adjustment of the impedance diagrams, we can see that the tempering treatment decreases the load transfer resistance and increases the constant phase element.

| Steel       | CPE.YO (F)   | Rp (Ω)  | Rs (Ω)  | n    |
|-------------|--------------|---------|---------|------|
| X80 Rolled  | 9.20.10⁻⁶    | 49238   | 12.015  | 0.99921 |
| X80 Tempered| 1.70.10⁻⁵    | 37356   | 13.730  | 0.99352 |
3.3 optical micrographs of the corroded surfaces
Figure 5 shows the optical micrographs of rolled steel and tempered steel after corrosion testing in 3.5% NaCl solution at 25°C. We can see that pitting corrosion is strongly pronounced in rolled steel, tempered steel has good resistance to corrosion in interaction with the medium.

![Optical micrographs of the corroded surfaces](image)

**Figure 5.** Optical micrographs of the corroded surfaces (a) Rolled X80 steel (b) Tempered X80 steel.

4. Conclusion
This study focuses on the corrosion behavior of rolled and tempered X80 steels. The following conclusions can be drawn:
- Both steels have a ferritic-pearlitic structure, which becomes finer after tempering.
- Potentiodynamic polarization tests show that the tempered steel has a low corrosion current density compared to rolled steel.
- Electrochemical impedance measurements show that the tempered steel has a high charge transfer resistance and a low constant phase element.
- Micrographs after corrosion tests show a high percentage of corrosion pitting in the structure of the rolled steel

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