# CORROSION RESISTANCE ON THE AUSTENITIC-FERRITIC STAINLESS STEEL SEW 410 Nr. 14517 CONTAINING NIOBIUM

# *RESISTÊNCIA À CORROSÃO DO AÇO INOXIDÁVEL AUSTENO-FERRÍTICO SEW 410 Nr. 14517 CONTENDO NIÓBIO*

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## ABSTRACT

The research of new stainless steel to use in chemical and oil industry has been constant in the last years. In this case, the austenitic-ferritic stainless steels are materials that present a better combination of mechanical properties and stress corrosion resistance than ferritic or austenitic ones. The microstructure constituted by elongated grains of austenite with alternate regions of ferrite and sigma phase depends on their chemical composition and heat treatment. Sigma phase, rich in chromium and molybdenum, is formed mainly during heating at 600 to 900 ºC. According to the literature, niobium has a great influence in the transformation of austenitic and ferritic phases of the duplex stainless steels, besides promoting grain refinement in the microstructure. In this work, the microstructure, microhardness, pitting potential, and electrochemical impedance of the SEW 410 Nr.14517 stainless steel containing 0,2% and 0,5% niobium it were analyzed. The preliminary results after the heat treatment showed that niobium favored the sigma phase transformation with significant hardness increasing. In relation to electrochemical tests, the corrosion resistance and the charge transfer resistance decreased with the niobium addition.

**Key words:** austenitic-ferritic stainless steels, sigma phase, pitting potential.

## *RESUMO*

*A pesquisa de novos aços inoxidáveis para utilização na indústria química e de petróleo tem sido constante nos últimos anos. Neste caso, os aços inoxidáveis austeno-ferríticos são materiais que apresentam uma melhor combinação de propriedades mecânicas e resistência à corrosão sob tensão que os aços inoxidáveis austeníticos e ferríticos. A microestrutura constituída de grãos alongados de austenita com regiões alternadas de ferrita e fase sigma depende da composição química e tratamento térmico. A fase sigma, rica em cromo e molibdênio, é formada principalmente durante aquecimento na faixa de temperatura entre 600 to 900 ºC. Conforme a literatura, nióbio tem uma grande influência na transformação das fases ferríticas e austeníticas dos aços duplex, além de o refino de grão da microestrutura. Neste trabalho, a microestrutura, microdureza, potencial de pitting e impedância eletroquímica do aço inoxidável austeno-ferrítico SEW 410 Nr.14517 contendo 0,2% e 0,5% de nióbio foram analisadas. Os resultados preliminares mostraram que após o aquecimento o nióbio favoreceu a transformação da fase sigma com aumento significativo da dureza. Com relação aos ensaios eletroquímicos, a resistência à corrosão e a resistência de transferência de carga diminuíram com o aumento do teor de nióbio.*

***Palavras-chave****: aço inoxidável austeno-ferrítico, fase sigma, potencial de pite.*

## INTRODUCTION

The research of new stainless steel to use in chemical and oil industry has been constant in the last few years. In this case, the austenitic-ferritic or duplex stainless steels are materials that present a better combination of mechanical properties and stress corrosion resistance than ferritic or austenitic stainless steels (CLAYTON and MARTIN, 1989). Nowadays, the austenitic-ferritic stainless steels is replacing the austenitic ones, in many applications as chemical and oil industry due to the optimum compromise between mechanical properties and corrosion resistance. In this case, the erosion-corrosion effect associated to salt environment should be prevented to reduce equipments maintenance costs. In the austenitic-ferritic stainless steels, the chemical composition and the thermal-mechanical deformation influence the final mechanical properties. The morphology of the constituent phases changes from a dendritic structure, in the as-cast material, to an elongated grain or ‘‘pancake’’ type of structure with alternate regions of ferrite and sigma phases in the wrought steel (IZA-MENDIA, 1998). The aspect ratio of both phases depends on the imposed hot reduction and strain. Besides the different mechanical properties of the phases, ductility and the deformation behaviors is modified by the presence of sigma phase. Sigma phase, rich in chromium and molybdenum intermetallic, is formed mainly during delta eutectoid decomposition. The areas surrounding the precipitates are depleted in these chemical elements and, therefore, potentially more susceptible to localized corrosion besides impairing toughness (GUNN, 2002). The volume of the depleted zone and the associated minimum alloy content will depend on the volume of the sigma phase, the temperature at which precipitation has occurred and the temperature-time relationship (NORSTRÖN, 1981; KAWALLA, 2000). At higher temperature (e.g. 1000 °C), the diffusion coefficient can be sufficiently fast to replenish partially the loss of alloying elements to the intermetallic particle but replenishment is less effective at lower temperatures. Accordingly, a material with the same volume fraction of sigma phase, but produced at two different temperatures could exhibit quite different critical pitting temperatures (CPT). Percolation theory was used to the explain the dependence of depth of pitting attack in chlorinated seawater on sigma phase content, with particle size being an important factor (FRANCIS and WARBURTON, 1995). The transformation behaviors of the ferrite and the austenite inside the duplex structure are modified by the presence of the other chemical elements. According to the literature, niobium has a great influence in the transformation of austenitic and ferritic phases of the duplex stainless steels, besides promoting grain refinement in the microstructure (ROSSITI, 2000). In this article, analysis were made and provided a basis for comparison about duplex stainless steel SEW 410 Nr. 14517 containing niobium.

## MATERIALS AND METHODS

The proposal of this study was to evaluate the effect of niobium in the austenitic-ferritic stainless steel SEW 410 Nr. 14517 (Cr26Ni6Mo3Cu3). Two ingots containing 0.2 and 0.5% niobium were melted in a vacuum-protection electrical induction furnace. The chemical compositions are presented in Table 1. Samples of the steels were annealed at 1050ºC to homogenize the cast structure. Then, they were heated at 845$^{o}$C, during fifteen, thirty and sixty minutes to evaluate the niobium effect on microstructure transformation. The volumetric fractions of the phases were determined by optical microscopy with image analysis. Microhardness measurements were carried out besides, pitting potential and electrochemical impedance tests in 3.5% NaCl solution. The corrosion tests were determined using an electrochemical system with a coupled microcomputer to acquisition and data analysis.

## RESULTS

The chemical compositions of the steels are summarized on Table 1. The values are in agreement with the SEW 410 Nr. 14517 standards specifications. The amounts of phases in the steels, after the different times of thermal treatments, are presented on Table 2.

**Table 1.** Chemical compositions of the stainless steels containing niobium (% weight).

| | **C** | **Cr** | **Ni** | **Mo** | **Cu** | **Mn** | **Si** | **Nb** | **N** | **P** | **S** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SEW 0.2** | 0.03 | 26.0 | 6.5 | 3.2 | 2,9 | 1.3 | 0.7 | 0.2 | 0.21 | 0.03 | 0.01 |
| **SEW 0.5** | 0.03 | 26.0 | 6.3 | 3.2 | 3.0 | 1.4 | 0.8 | 0.5 | 0.21 | 0.03 | 0.01 |

**Table 2.** The amount of phases in the austenitic-ferritic stainless steel SEW 410 containing niobium after heat treatment at 850°C during 15, 30 and 60 minutes.

| | **SEW 410 0.2 Nb** | | | **SEW 410 0.5Nb** | | |
|---|---|---|---|---|---|---|
| Time | Austenite | Ferrite | Sigma | Austenite | Ferrite | Sigma |
| 15 | 47 ± 3 | 45 ± 5 | 8 ± 3 | 44 ± 3 | 46 ± 4 | 10 ± 5 |
| 30 | 45 ± 4 | 40 ± 4 | 15 ± 4 | 42 ± 5 | 40 ± 5 | 18 ± 5 |
| 60 | 42 ± 4 | 18 ± 5 | 40 ± 4 | 43 ± 5 | 12 ± 5 | 45 ± 3 |

The microstructure of the samples annealed at 1050ºC and heat treated at 850°C at different times are presented in the Figures 1 and 2.

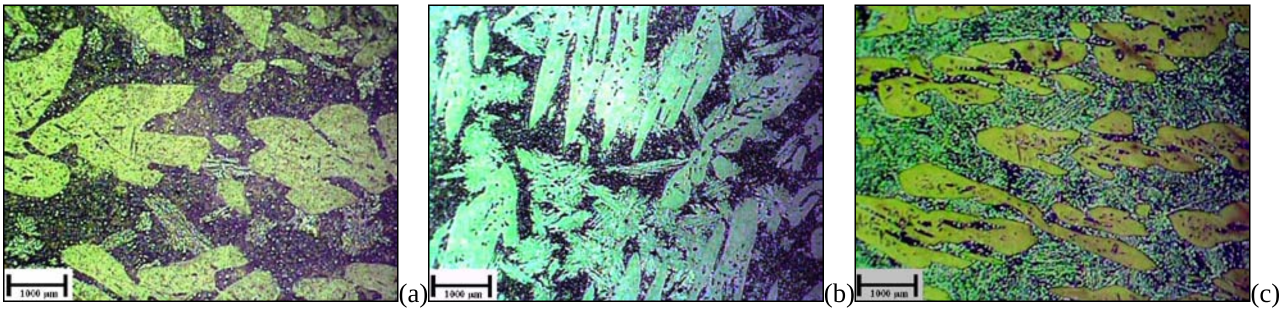

**Figure 1.** Austenitic-ferritic stainless steel with 0.2 Nb. **(a)** Heat treated during 15 min. Yellow grains of austenite and small points of sigma in brown matrix of ferrite. **(b)** Heat treated by 30 min. Sigma phase rich in chromium and molybdenum intermetallic grows from γ/α interface. (**c**) After heat treatment during 60 min the microstructure presents austenite and sigma associated with little quantity of ferrite.

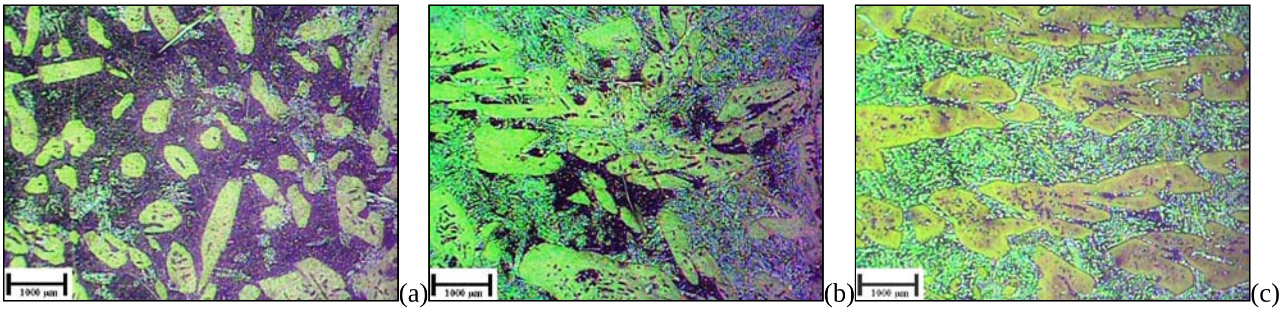

**Figure 2**. Austenitic-ferritic stainless steel with 0.5 Nb heat treated during 15 min (a), 30 min (b) and 60 min (c). For all conditions the microstructure is similar that presented in the Figure 1. However there is a little more ferrite because the increase of niobium in the steel.

In the Table 3 are presented the values of Vickers microhardness (HV) of the steels after heat treatment at 850°C during 15, 30 and 60 min.

**Table 3**. Values of Vickers microhardness (HV) of the steels after heat treatment at 850°C during 15, 30 and 60 minutes.

| Time (min) | Ferrite + $\sigma$ 0.2Nb (HV) | Ferrite + $\sigma$ 0.5Nb (HV) | Austenite 0.2 Nb (HV) | Austenite 0.5 Nb (HV) |
|---|---|---|---|---|
| 15 | 362 ± 21 | 355 ± 17 | 262 ± 12 | 276 ± 15 |
| 30 | 572 ± 16 | 575 ± 18 | 292 ± 10 | 296 ± 20 |
| 60 | 605 ± 29 | 609 ± 06 | 283 ± 07 | 290 ± 09 |

The potentiodynamic polarization curves were obtained and comparisons between the pitting potentials are listed in the Table 4. The tests were carried out in 3.5% NaCl solution at room temperature.

**Table 4**. Pitting potential in the austenitic-ferritic stainless steels after heat treatment at 850°C during 15, 30 and 60 minutes.

| SEW 410 | Pitting potential (V) SEW 410 (0.2 Nb) | Pitting potential (V) SEW 410 (0.5 Nb) |
|---|---|---|
| 15 min | 1,16 ± 0,01 | 1,21± 0,01 |
| 30 min | 0.55 ± 0,05 | 0.65± 0,04 |
| 60 min | 0,92 ± 0,03 | 0,22 ± 0,03 |

In relation to electrochemical impedance tests, the spectra and the values of the charge transfer resistance of the stainless steel containing 0.5% Nb are observed in the Figure 3.

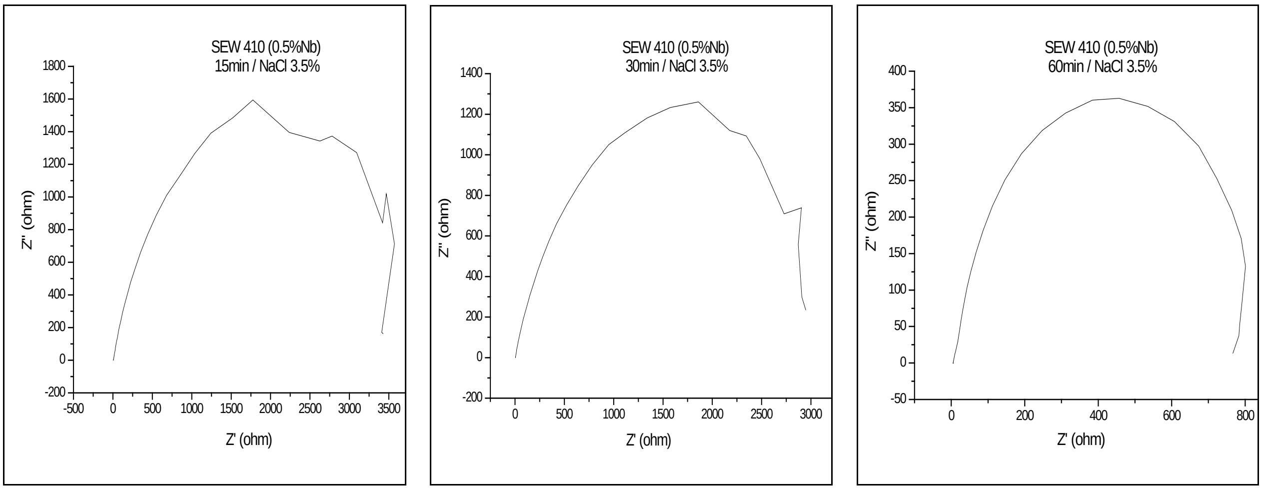

**Figure 3**. Electrochemical impedance tests and the Nyquist diagrams of austenitic-ferritic stainless steel containing 0.5% Nb heat treated during 15 min (a), 30 min (b) and 60 min (c).

## 4- DISCUSSION

The specimens of austenitic-ferritic stainless steel SEW 410 containing 0.2 and 0.5% niobium observed by microscopy show in the Figures 1 and 2, the austenite and ferrite phases besides sigma precipitates. The volumetric percentages of sigma phase increase while the ferritic phase decreases, when the heat treatment time and niobium level increase. Microstructure as Figure 1c and 2c show austenite islands and sigma phase with minus ferritic phase after heat treatment during sixty minutes. In relation to the microhardness the values increased with amount of sigma. As the literature the areas surrounding the sigma precipitates are depleted in molybdenum and chromium, therefore, potentially more susceptible to localized corrosion as the Table 4. The pitting potential values listed decreased with volumetric percentages of sigma. Regarding the results of electrochemical impedance observed in the Figures 3, the charge transfer resistances of the austenitic-ferritic stainless steels containing 0.5%niobium decreased when the sigma phase increased. Similar spectra were obtained with steel containing 0.2%niobium, and the charge transfer resistance decreases when the niobium increases. The results shows that the sigma phase promotes hardness increase and corrosion resistance decrease. So, it is important to evaluate the work conditions of a component manufactured with this steel to optimize their use in situations in which wear is fundamental since there is a potential control of the saline environment.

## CONCLUSIONS

- The niobium and sigma phase promoted a hardness increasing in the duplex stainless steel.
- The niobium addiction promoted the increasing of sigma phase transformation.
- Sigma phase increased when the time of heat treatment increased too.
- The values of pitting potential and charge transfer resistances decreased with the volumetric percentages of sigma.

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