

# The Effect of Heat Treatment and Corrosion Behavior of AISI420

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**Abstract.** The present paper shows the effect of heat treatments applied to an AISI 420 steel. The characterization of corrosion behavior of AISI 420 steel, in 0.5M NaCl aqueous solution, was made in an electrochemical cell with 3 electrodes, connected at PG STAT 302N Autolab Potentiostat, at laboratory temperature. The medium used was a NaCl 0.5M solution with a pH of 6.26 and an electro-conductivity by 49.9 mS/cm.

## 1. Introduction

The foundation of modern industry is stainless steel due to its mixt application in aqueous corrosive environments in a significant number of industries [1, 2]. High volume production and advance manufacturing techniques of stainless steels has resulted in the availability of cost effective and corrosion resistant steels [3]. Austenitic stainless steels grades generally have strong corrosion resistance in mildly corrosive acid, industrial and marine environments [4, 5]. Martensitic stainless steels have good mechanical properties and strong resistance to surface deterioration.

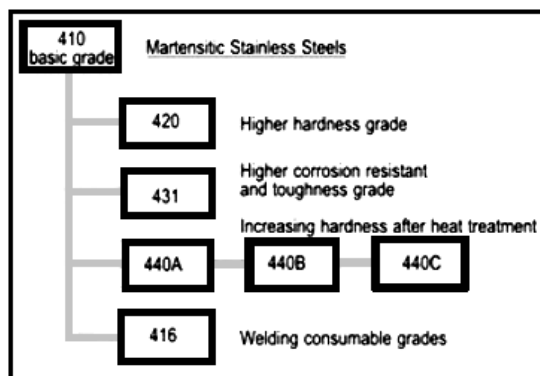


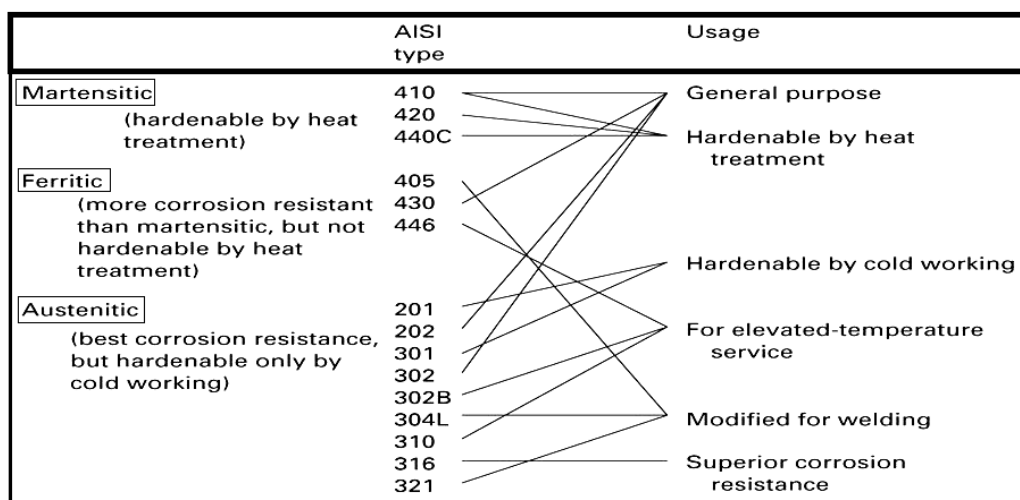
Figure 1. Martensitic stainless steels [6].



The need for superior corrosion resistant properties in specific industrial applications necessitates performance improvement on the surface property and metallurgy of these steels [7-9]. Altering the microstructure of stainless steel significantly improves their corrosion resistance. Microstructural constituents such as grain size, phases, precipitates, flaws and inclusions are strongly modified by heat treatment to effect changes in their mechanical, chemical and surface properties based on the martensite/austenite formation, changes in grain size and defects [10, 14-16]. Choi et al (2007) studied the relationship between different austenitizing temperature of 0.3C-14Cr-3Mo type stainless steel and their electrochemical performance in Cl containing neutral aqueous solutions. He observed that increase in austenitizing temperature caused a proportionate increase in corrosion and pitting potential of martensitic steel due to precipitation of fewer types of carbide among the steel matrix after high temperature austenitization [11].

## 2. Materials and methods

Previous researches on the effect of heat treatment processes on the corrosion resistance of stainless steel have given mixed results. Nasery et al (2011) studied the effects of austenitizing temperature, tempering temperature and time, and on the microstructure, mechanical and corrosion properties of AISI420 martensitic steel, see Figure 2.



**Figure 2.** Usage stainless steels.

Results showed that the temperature significantly influenced the mechanical properties of the steel. The effects of heat treatment on microstructure, hardness uniformity, surface roughness and corrosion resistance of a 13Cr-type martensitic stainless steel was studied by means of optical microscopy, scanning and transmission electron microscopy and polarization resistance. Observation showed that the corrosion resistance of the steels reduced after tempering in comparison to quenching [12].

The cycle control of heat treatments, on the quenching and tempering operation of AISI 420 stainless steel, is essential for improved material performance. The adequate choice of heat treatment parameters, can lead an optimization on its mechanical properties and corrosion resistance. Thus, this paper aims to investigate the effects of quenchants medium, and austenitizing and tempering temperatures, on the microstructure and mechanical properties of AISI 420 steel.

The composition was determined with an optical spectrometer, Foundry Masters, using iron analysis base, with  $\pm 3\%$  accuracy of results. The sample subjected to analysis was processed from laminated bar and prepared by cutting on lathe. The determination of chemical composition, by quantitative spectral analysis, was made in 3 various points from prepared surface. Based on measured percents, the specific software made an average of registered values, see Table 1, with are present in analysis bulletin.

**Table 1.** Chemical composition determined by spectral analysis.

<i>Fe</i>	<i>Cr</i>	<i>Mn</i>	<i>Si</i>	<i>C</i>	<i>Ni</i>	<i>Mo</i>	<i>W</i>
<b>86.50</b>	<b>12.10</b>	<b>0.29</b>	0.24	0.23	0.18	0.10	0.07
Cu	V	Co	P	S	Al	Nb	Ti
0.07	0.05	0.02	0.01	0.01	< 0.01	< 0.01	< 0.01

Based on analysis bulletin obtained, the studied alloy is part of martensitic stainless steels classes, type AISI 420 (20Cr120) or 1.4021.

Based on percents of alloying elements and it is established the following heat treatments parameters [9-11], which can be applied to AISI 420 steel according to Table 2.

**Table 2.** Parameters of heat treatments applied to AISI 420 steel.

<i>Symbol</i>	<i>Heat treatment</i>	<i>Heating temperature</i> [°C]	<i>Heating speed</i> [°C/min]	<i>Heating medium</i>	<i>Maintaining time</i> [min]	<i>Maintaining temperature</i> [°C]	<i>Cooling speed</i>	<i>Cooling medium</i>
AISI 420 (I)	Initial state	Laminated bar, obtained by continuous casting and calibrated at standard dimensions imposed by beneficiaries.						
AISI 420 (A)	Annealing	770	10	Air	20	770	Slow	Furnace
AISI 420 (Q)	Martensitic quenching	1000	10		30	1000	Rapid	Water
<b>AISI 420 (T)</b>	High tempering	700	10		60	700	Free	Air

The heat treatments was made in laboratory conditions, using standard samples, with dimensions which permit their utilization both in preparation operations by polishing and chemical attack, also by SEM, X-ray diffractometry and corrosion behavior in 0.5M NaCl aqueous solution.

The heating and maintaining operations of effectuated heat treatments, was realized in an electric furnace, with fixed hearth, CE12 UTTIS model, controlled according the heat treatment diagram, with a specific software Protherm.

### 3. Results and discussions

The electrochemical behavior of AISI 420 steel was evaluated using a electrochemical cell with 3 electrodes, connected at Autolab PG STAT 302N potentiostat. The medium used was a NaCl 0.5M solution with a pH of 6.26 and an electro-conductivity by 49.9 mS/cm.

In the Table 3 it is shown the extension of each potential domain for each sample and the mentioned characteristics on voltametric behavior.

**Table 3.** The characteristics of voltametric behavior on extended potential domain of samples by AISI 420 steel, in 0.5M NaCl solution.

<i>Sample</i>	<i>Domain I</i> [V]	<i>E<sub>BD</sub></i> [V]	<i>Domain II</i> [V]	<i>p<sub>1</sub></i> [mA/cm <sup>2</sup> ·V]	<i>p<sub>2</sub></i> [mA/cm <sup>2</sup> ·V]
A	- 0.3876 ... 0.0792	0.1256	0.1549 ... 3.000	2.4214	75.02
C	- 0.3360 ... 0.1012	0.1280	0.1695 ... 3.000	1.0399	76.00
D	- 0.3226 ... 0.1878	0.2586	0.1695 ... 3.000	1.2356	59.63
B	- 0.2576 ... 0.0906	0.1077	0.1297 ... 3.000	0.4545	44.52

Based on the presented data from Table 1 we can draw the following conclusions:

- The value of potential in open circuit (inferior limits of domain I) show that the order of corrosion resistance in 0.5M NaCl for the 4 samples is the following: sample B > sample D > sample C > sample A, while the breakdown potential for AISI 420 steel is small, for A and C is similarly, and the higher is for D sample.

- The value of p1 which considers the behavior on first potential domain concerning the variation of current density with potential modifications applied to sample, the speed of anodic process increase in the following order: B < C < D < A;

- The value of p2 highlight the corrosion resistance of the 4 samples after passing the breakdown potential, when the density of anodic current increase in the order: B < D < A < C.

On the OCP to + 1.2 V ... -1.2 V to OCP interval the cyclic voltammograms were drawn, starting from the potential in open circuit in anodic direction until 1.2V, then in return scanning is modified the potential at -1.2V, then return at the potential from which are going.

Based on the obtained data from potentiodynamic curves [13], using the corrosion program from Nova 1.10 software, we have obtained the Tafel coefficients ( $b_a$  and  $b_c$ ), the corrosion potential ( $E_{cor,calc}$ ) defined at the intersection of Tafel curves (anodic and cathodic branch), which is moving at negative values (with 11 to 26 mV) between OCP, this is due to the medium aggressivity, density of corrosion current ( $j_{cor}$ ), corrosion speed ( $v_{cor}$ ) and polarization resistance ( $R_p$ ), all being presented in Table 2. In the evaluation of the corrosion speed, it is considered the current density ( $j$ ), defined by Butler-Volmer relation that being:

$$j = j_{cor} \cdot \left[ \exp\left(\frac{2.303 \cdot (E - E_{cor})}{b_a}\right) - \exp\left(-\frac{2.303 \cdot (E - E_{cor})}{b_c}\right) \right] \quad (1)$$

In which  $b_a$  and  $b_c$  are Tafel slopes:

$$b_a = \frac{R \cdot T}{\alpha \cdot n \cdot F} \quad (2)$$

Respectively:

$$b_c = \frac{R \cdot T}{(1 - \alpha) \cdot n \cdot F} \quad (3)$$

**Table 4.** Corrosion parameters of analyzed samples on 0.5M NaCl aqueous solution.

Parameters	Measurement units	Samples			
		AISI 420 (A)	AISI 420 (B)	AISI 420 (C)	AISI 420 (D)
S	[cm <sup>2</sup> ]	2.1372	2.7264	2.5491	4.6434
- OCP	[mV]	384	323	321	240
$b_a$	[mV/dec]	296.0	141.8	197.3	115.5
$b_c$	[mV/dec]	207.8	200.6	284.4	185.8
- $E_{cor,calc}$	[mV]	395.9	334.5	336.2	265.6
$j_{cor}$	[μA/cm <sup>2</sup> ]	32.156	6.445	10.872	3.262
$v_{cor}$	[mm/an]	0.3736	0.0749	0.1263	0.0379
$R_p$	[Ω]	772	2053	1336	2042

The data presented in Table 4, both by OCP value and the corrosion speed, confirm that the AISI 420 (B) sample is much resistant at corrosion, sample A is much attackable; the order of the 4 samples according with the increase of corrosion resistance being: B > C > D > A.

The value of polarization resistance from Table 2 confirm that A sample is much attackable, also the higher value of corrosion resistance is for C, but similarly with B sample.

For characterize the behavior of the 4 steel sample is used and the electrochemical impedance spectroscopy by drawing the spectrums, after their immersion in aggressive medium and achievement of a stationary state for system (at potential in open circuit).

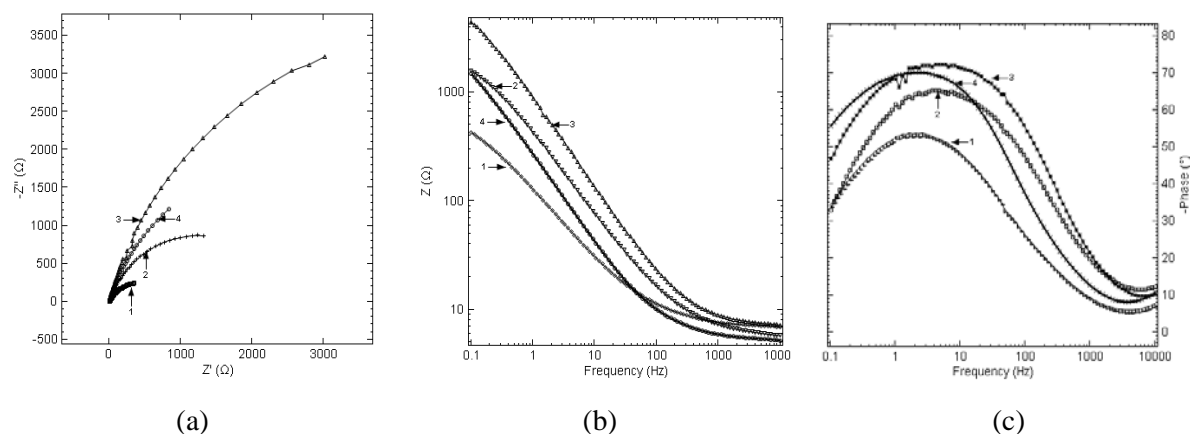
The obtained spectrums at potential in open circuit, at amplitude of alternative current by 10 mV and in a frequency domain by 10-1 to 104 Hz, are present in Figure 3.

For interpretation of data is used an equivalent electric circuit giving by Boukamp model by data fitting with “Electrochemical circle fit”, being the circuit by which the experimental data are similar with the fitted data and in which the calculated sizes are:  $R_s$  ohmic fall from solution or uncompensated resistance;  $R_p$  polarization resistance; CPE element of constant phase, defined by:

$$Z_{CPE} = \frac{1}{Y_0 \cdot (j \cdot \omega)^N} \quad (4)$$

Where:  $Y_0$  is admittance,  $\omega$  angular frequency of alternative current,  $j=(-1)^{1/2}$  and  $N$  is the exponent of the element by constant phase.

The CPE presence in equivalent circuit is the proof of surface heterogeneity and the diffusion processes which is taking place.



**Figure 3.** Spectrums of electrochemical impedance for the 4 steel samples: (a) Nyquist representations; (b) and (c) Bode representations.

The polarization resistances calculated by electrochemical impedance spectroscopy are different of the potentiodynamic polarization curves, due to the different time of immersion both to realize the stationary state for OCP achievement and the time necessary to drawing the spectrums of electrochemical impedance, this explains the high values obtained by electrochemical impedance spectroscopy.

**Table 5.** Experimental data obtained by electrochemical impedance spectroscopy.

Sample	CPE	N	$R_p$	$R_s$	$\phi$
	[ $\mu F$ ]	-	[ $\Omega$ ]	[ $\Omega$ ]	[ $^\circ$ ]
AISI 420 (A)	1960.20	0.9946	812	7.48	53.7
AISI 420 (C)	570.12	0.9962	2453	6.42	65.2
AISI 420 (D)	167.73	0.9968	9489	6.90	72.2
AISI 420 (B)	311.73	0.9965	5106	5.18	70.1

The order of corrosion resistance increase from electrochemical impedance spectroscopy is the following:  $A < C < B < D$ .

The presence in given medium of  $\text{Cl}^-$  ions amplify the corrosion process due to their absorption both in active surface and passive in electrode surface, the proof being and the 2 control mechanisms of corrosion highlighted by electrochemical impedance spectroscopy.

A quantitative appraisal of corrosion process for steel in considered medium can be realized by drawing of potentiodynamic curves on  $\pm 0.15$  V domains towards by OCP at a small speed of potential.

#### 4. Conclusions

The polarization resistances calculated by electrochemical impedance spectroscopy are different of the potentiodynamic polarization curves, due to the different time of immersion both to realize the stationary state for OCP achievement and the time necessary to drawing the spectrums of electrochemical impedance, this explain the high values obtained by electrochemical impedance spectroscopy.

The comparative study realized on AISI420 stainless steel, after heat treatments, highlight that by modern methods can be establish the link between microstructure – phases – hardness – corrosion resistance.

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