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Electrochemical Evaluation of AISI 420 Steel after Several Heat Treatments

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The paper deals with the study of the electrochemical behavior of a heat treated AISI 420 martensitic stainless steel, usually used on surgical instruments. According to the alloy composition we designed the heat treatment procedures with specific parameters in order to enhance the properties of the alloy. The heat treatments involved are: Annealing at 770 °C with maintaining 20 min followed by slow cooling in furnace; martensitic quenching at 1000 °C with maintaining 30 min followed by rapid cooling in water, and high tempering at 700 °C with maintaining for 60 min followed by free cooling in open air. The characterization of electrochemical behavior of AISI 420 steel was done in a 0.5 M NaCl aqueous solution. The study concluded that by applying high tempering a decrease of hardness and an increase of mechanical properties is obtained. Also high tempering induces a better corrosion resistance for our studied alloy.

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PACS/topics: AISI 420 steel, heat treatments, electrochemical impedance spectroscopy, enhanced corrosion resistance

1. Introduction

The AISI 420 steel is a martensitic type stainless steel and is often used in medical field as surgical instruments, but also as valves and cutting parts. The alloy has a higher content of carbon compared to other and the hardness is increased. Using other alloying elements, the corrosion resistance can be improved (Mo, Cu), respectively the oxidation resistance at high temperatures (Si, Al, W, Mo), and finally the mechanical characteristics at high and low temperatures (W, Mo, Nb, Co) [1–3]. The stainless steels, usually, are used at temperatures up to 800 °C.

In order to change the structure and to modify the characteristics a classical heat treatment can be applied. According to the nature and composition of the steel phase's transformations in solid state can occur. The martensitic quenching heat treatments is applied to the steels with more 0.25 %C, which present, in solid domain, an allotropic transformation of gamma iron to alpha iron [1–9]. Usually, the high tempering consists in heating up to 800 °C which determines a hardening, due to formation of gamma phase. Because, the martensitic quenching and high tempering weaken the steels, the heat treatment cannot be applied to the parts subjected to intensive loads [6–19].

In previous studies we have evaluated the hardness of the alloys [4, 5]. In casted-laminated form the alloy (samples A) has an average hardness of 163 HB, very close to the annealed state (samples B), and after the martensitic quenching (samples C) the value is 700 HB and after high tempering (samples D) is around 280. Also using XRD [4, 5] we identified that the major phase in alloy is: $Cr_{0.7}Fe_{0.3}$ with cubic crystalline network (peak at $2\theta = 44.563°$) with changes on the samples after quenching or high tempering with a major phase of $Cr_{0.26}Fe_{1.74}$ with cubic crystalline network (peak at $2\theta = 44.467°$) and respectively $Cr_{0.109}Fe_{0.891}$ with cubic crystalline network (peak at $2\theta = 44.605°$).

In present paper we studied the AISI 420 steels, in cast state but also after 3 heat treatments: annealing, martensitic quenching, and high tempering, with determination of structure, properties and respectively the evaluation of the corrosion behavior using spectroscopy of electrochemical impedance (SIE).

2. Experimental part

The alloy involved in the study is part of martensitic stainless steels classes, type AISI 420 (20Cr120) or 1.4021 and has the following composition: C 0.23, Si 0.24, Mn 0.29, Cr 12.10, Mo 0.10, P < 0.01, S < 0.01, and the difference to 100 is Fe. The composition was determined with an optical spectrometer, Foundry Masters. The heat treatments were done in laboratory conditions,

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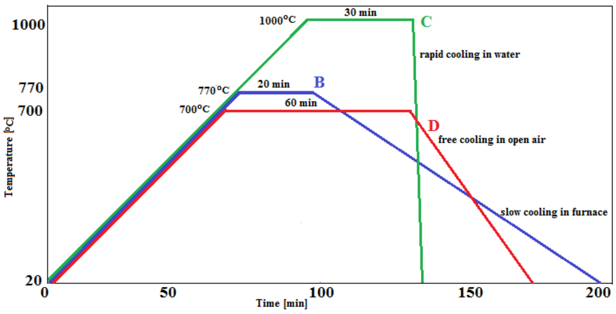

Fig. 1. The heat treatment applied to the samples: B — annealing at 770 °C with maintaining 20 min followed by slow cooling in furnace, C — martensitic quenching at 1000 °C with maintaining 30 min followed by rapid cooling in water, D — high tempering at 700 °C with maintaining for 60 min followed by free cooling in open air (heating rate 10 °C/min).

starting from untreated samples A. The electric furnace used is a CE12 UTTIS model, controlled according the heat treatment diagram (Fig. 1), with a specific software Protherm.

The characterization of electrochemical behavior of AISI 420 steel was made at the laboratory temperature (25 ± 1 °C), using a electrochemical cell with 3 electrodes, connected at Autolab PG STAT 302N potentiostat, which have the Nova 1.10 software in his composition.

The NaCl 0.5 M solution, used as aggressive medium had a pH of 6.26 and an electro-conductivity by 49.9 mS/cm. Before each determination, the work electrode was polished than degreased and washed with bidistilled water.

3. Results and discussions

The anodic behavior of the steel samples on an extended potential domain until 3.00 V, starting with the open circuit potential (OCP) for each sample, is presented in Fig. 2.

For each sample can be distinguished 2 linear domains (I and II) at the intersection of which is the point which corresponds to breakdown potential (E_{BD}), after which the gradient of anodic process ($\mathrm{d}j/\mathrm{d}E$) is much higher (p_2) compared to the slope of the first potential domain (p_1). The voltametric behavior of A and C samples, on the extended potential domain is similar, the curves (1) and (2) (Fig. 2). After the breakdown potential, the linear dependence of current density shows that the corrosion process is continuous for each sample.

After the drawing of the linear voltammograms, both on the electrode and in the solution, the corrosion products are green precipitates, and the pH of solution is higher than 8.5, the electro-conductivity decreased with one unit (< 48.9 mS/cm).

In Fig. 3 there are present the cyclic voltammograms for the 4 samples at scanning speed by 50 mV/s.

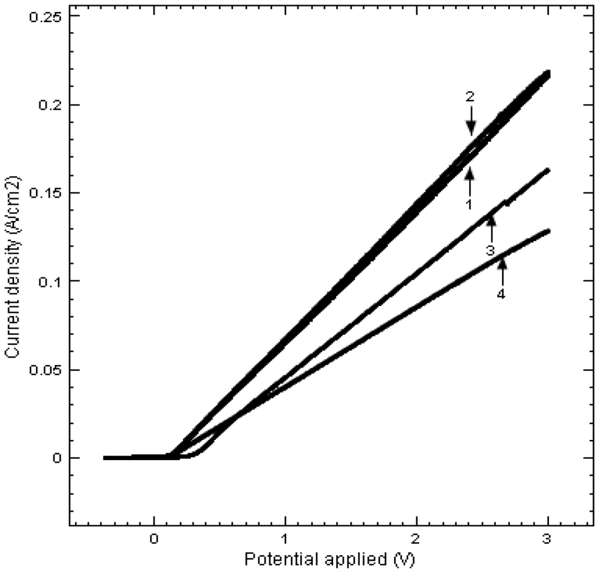

Fig. 2. Dependence of current density of applied potential on extended domain for the 4 samples at scanning speed of potential by 50 mV/s.

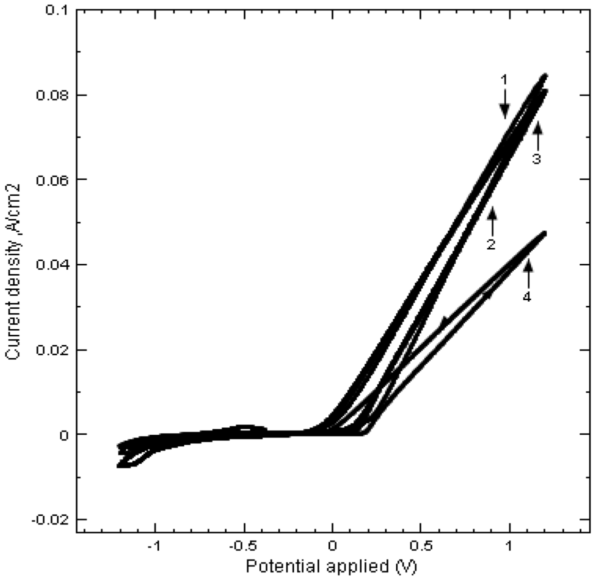

Fig. 3. Cyclic voltammograms obtained in 0.5 M NaCl solution at 50 mV/s for the 4 steel samples.

The cyclic voltammograms (CV) for the 4 samples, on mentioned domain, have highlighted the pitting corrosion. At the return scanning of potential appears a characteristic hysteresis of this type of corrosion [20–27].

Like in linear voltammograms, there appears a pronounced modification of current density at breakdown potential, followed by a linear increase of current density with applied potential, after which the return scanning for each sample can highlight the corrosion in points, formed that hysteresis of modifications for current density with the potential (presented in Fig. 3 on curve (4) by arrows).

We can observe from the cyclic voltammograms (Fig. 3) on the OCT interval $(+1.2\ \text{V} \div -1.2\ \text{V})$, that the anodic process is intensified due to current density increase. Second (2) sample, which has small values, presents a higher corrosion resistance comparative with the other 3 samples.

A quantitative appraisal of corrosion process for steel in considered medium can be realized by drawing of potentio-dynamic curves on ± 0.15 V domains towards by OCP at a small speed of potential.

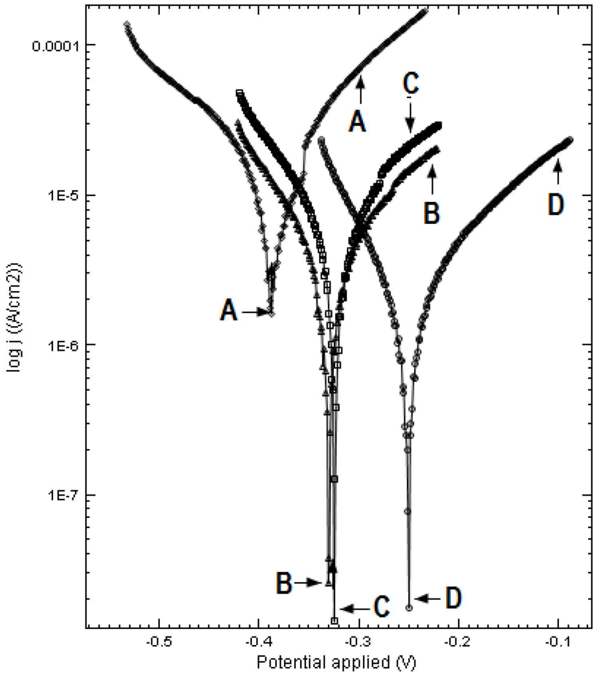

Fig. 4. Evans diagrams for the 4 steel samples in 0.5 M NaCl solution: A — cast state, B — annealed, C — martensitic quenching and D — high tempering.

From these data one can draw the Evans diagrams which enable calculus for the Tafel coefficients and corrosion parameters [17–24]. In Fig. 4 there are present the Evans diagrams for the 4 steel samples in 0.5 M NaCl solution, the modification speed of potential being by 1 mV/s.

The order of corrosion resistance increase from electrochemical impedance spectroscopy is the following: A (cast state) $<$ C (martensitic quenching) $<$ B (annealed) $<$ D (high tempering). Although the values for exponent by constant phase (N) show the capacitive character of corrosion process in aggressive medium, the values of phase angle prove the existence of a diffusive control for corrosion in given medium, the higher in the case of A sample, followed C sample, B sample and finally D sample.

Based on cyclic voltammograms one can say that on (OCP to $+1.2\ \text{V} \div -1.2$ V to OCP) interval, after breakdown potential, taking place an intensification of anodic process by a pronounced increase of current density, that for B sample have small values which means that present a good resistance at corrosion comparative with the other 3 samples.

4. Conclusions

After applying heat treatments, in order to increase the exploitation time for an AISI 420 steel industrial part, we got the following conclusions:

The AISI 420 steel is part of martensitic stainless steels class (with 0.2 to 0.4% carbon) and it is used to manufacture the industrial parts, just after application of improvement heat treatment. The structure obtained is composed by primary and secondary hard carbides in a martensitic mass. By applying the high tempering there is obtained a decrease of hardness and an increase of mechanical properties, completed by the reduction of internal tension obtained after quenching.

The polarization resistances calculated by electrochemical impedance spectroscopy are different of the potentio-dynamic 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 spectra of electrochemical impedance, this explains the high values obtained by electrochemical impedance spectroscopy.

The order of corrosion resistance increase from electrochemical impedance spectroscopy is the following: A (cast state) $<$ C (martensitic quenching) $<$ B (annealed) $<$ D (high tempering).

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