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ANALYSIS OF PITTING CORROSION ON AN INCONEL 718 ALLOY SUBMITTED TO HEAT TREATMENTS[1]

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Abstract
Inconel 718 is one of the most important superalloys, and it is mainly used in the aerospace field on account of its high mechanical strength, good resistance to fatigue and creep, good corrosion resistance and ability to operate continuously at elevated temperatures. In this work the resistance to pitting corrosion of a superalloy, Inconel 718, is analyzed before and after the double aging heat treatments. The used heat treatment increases the creep resistance of the alloy, which usually is used up to 0.6 T_m. Samples were subjected to pitting corrosion tests in chloride-containing aqueous solution, according to ASTM-F746-04. The results of these trials show that after heat treatment the superalloy presents lower values of pitting potential.
Key words: Double aging; Pitting corrosion; Inconel 718.

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1 INTRODUCTION

Since 1930 nickel base superalloys are mainly used in aerospace applications, due to their high mechanical resistance, good creep, fatigue and corrosion properties and potential to work in elevated temperatures. One of the most important superalloys, Inconel 718, has been used in nuclear, cryogenic, oil and mostly aerospace industries. For example Inconel 718 is the backbone of jet turbines, both civil and military. This superalloy has a Ni-Fe-Cr matrix and alloying elements that produce secondary phases such as $Ni_3(Al, Ti)$ (γ') gamma prime; Ni_3Nb (γ") gamma double prime, also eta (η) hexagon close packet Ni_3Ti; delta (δ) orthorhombic Ni_3Nb and other topologically close packed phases such as Laves and μ. Heat treatments such as double aging promotes increase its structural stability by inducing the precipitation of γ' and γ", which confers the mechanical resistance of Inconel 718.[1,2]
Due to the presence of chromium and aluminum and formation of their respective stable oxides, the passivation of the Inconel 718 surfaces is achieved, conferring its characteristic corrosion resistance. Metals that form passive layers are susceptible to localized corrosion (pitting), which consists in the formation of short extension and deep cavities. This kind of corrosion initiates due to the break of passivation film, usually in defects such as inclusions, dislocations, grain boundaries or other interfaces.
This work studies the pitting corrosion potencial for the superalloy Inconel 718, before and after double aging heat treatments. The samples were submited to corrosion tests by adaptation of the methods and procedures suggested in Yashiro et al.[3] and ASTM F746-04.[4]

2 EXPERIMENTAL PROCEDURE

The superalloy Inconel 718 was furnished by Multialloy Co. The chemical composition is described in Table 1. The material were produced via VIM/VAR, forging and solution treated.

Table 1. Chemical composition (wt. %) of Inconel 718

Inconel 718 (wt. %)								
Cr	Ni	Si	Mo	Ti	Nb	Fe	Al	C
18.94	54.47	0.04	1.35	1.05	5.89	17.99	0.27	0.03

The double aging heat treatment is described in table 2. The first step of heat treatment is solid solution, which promotes homogenization and redistribution of alloy elements. The aging step precipitates the secondary phases, mainly γ' and γ".

Table 2. Double aging heat treatment steps

Heat treatment steps	Parameters
Solid solution	1.095ºC; 1.0 h/AC
Double aging step	955ºC; 1.0 h/AC
	720ºC; 6.5 h/FC
	720ºC; 1.5 h/FC
	620ºC; 8.0 h/AC

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Conventional metallographic procedures of griding and polishing were used, before each corrosion testing. For the corrosion test an electrolytic cell with three electrodes was used: a working electrode (Inconel 718 with an exposed surface of 0.785 cm^2), a reference electrode of Ag/AgCl and a counter electrode of platinum. The corrosion medium was a 3.5% wt NaCl aqueous solution, without stirring, at ambient temperature and pH 6.05. The corrosion tests were conducted using an Autolab potentiostat/galvanostat, model PGSTAT30, interfaced to in a microcomputer via the USB-IF030 interface and controlled by the GPES software. . In order to characterize the pitting formation, the surfaces were analysed using Zeiss Axioscope Al Bio optical microscope,
Cyclic voltametry and chronoamperometric experiments were conduct to determine the breakdown potentials (E_b), potential at which a significant increase in the current was observed, and the pitting potentials (E_p), respectively. The cyclic voltametry experiments, were performed starting from -400 mV bellow de open circuit potential, after 01 of exposition to the electrolyte solution, varying the working electrode potential (5 mV/s) up to +400 mV the OCP, and reverting the potential to the starting one. The chronoamperometric experiments were also performed after 01 hour of the exposition of each surface to the electrolyte solution, starting with an applied potential E_1 ($E_1 \approx E_b$- 30 mV) and holding this potential for 120 s. Following this first experiment, the working electrode surface was freshly polished, exposed to the electrolyte solution for 01 hour, a potential E_2= (E_1+ 20mV) was applied and held for 120 s. The step 02 was repeated, increasing the applied potential at each step by 20 mV until and an increase in the current was observed.

3 RESULTS AND DISCUSSIONS

Figure 1 presents the cyclic voltamograms of the as received and duble aged Inconel 718 surfaces exposed to the chloride containing aqueous solutions The breakdown potential of the double aged Inconel 718 surfaces ($E_{b,(DA)}$) was 1.05V while that of the as received surfaces ($E_{b, (AR)}$) was 1.09V. These potentials indicate that with the double ageing treatment the Inconel 718 alloy becomes less nobler (smaller breakdown potential) than the alloy without heat treatment.

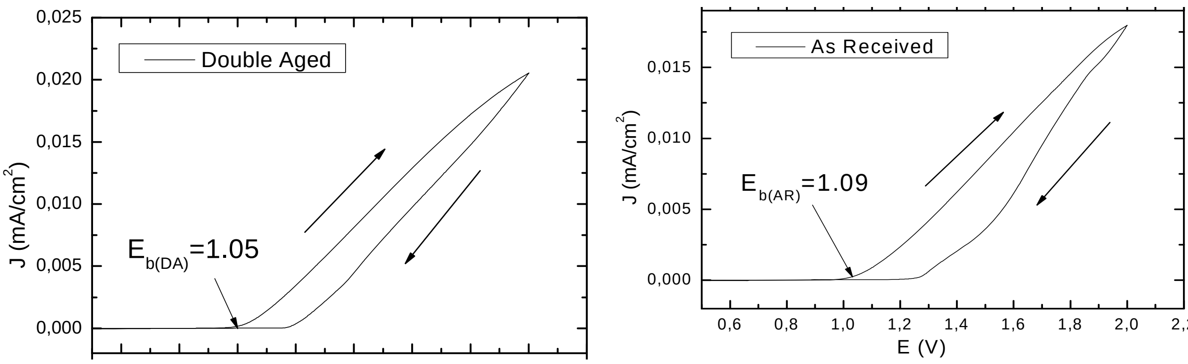

Figure 1. Cyclic voltamograms of double heated and as received Inconel 718 surfaces exposed to sodium chloride aqueous solution.

Figures 2 and 3 show the results of the chronoamperometric experiments performed for surfaces of the double aged and as received Inconel 718 surfaces, respectively, exposed to the sodium chloride solution.

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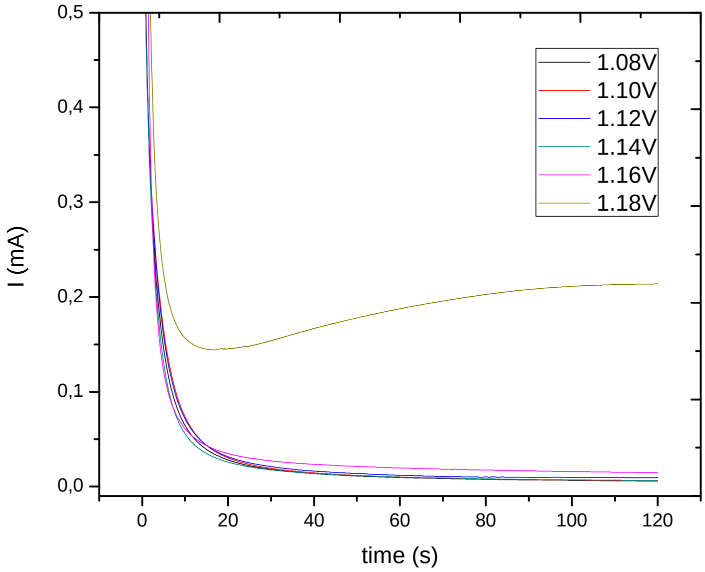

Figure 2. Chronoamperometric tests for as received Inconel 718 surfaces exposed to chloride containing aqueous solution.

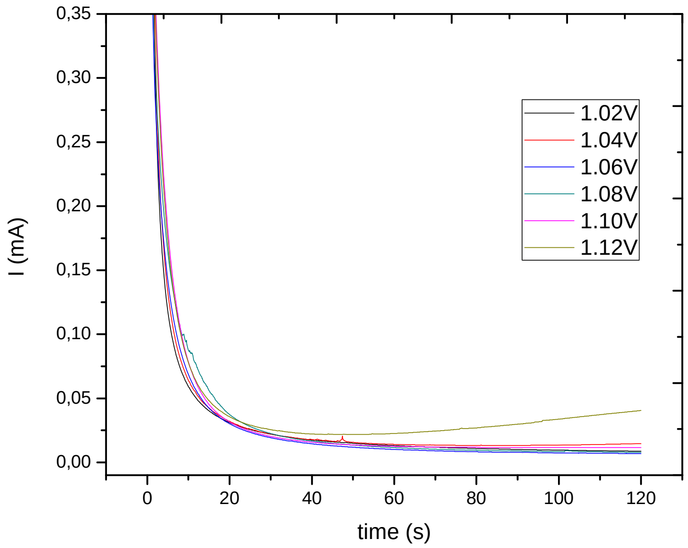

Figure 3. Chronoamperometric tests for double aged Inconel 718 surfaces exposed to chloride containing aqueous solution.

From the chronoamperometric tests it can be observed that for the as received Inconel 718 the pitting corrosion potential is 1.18V while for the aged sample it is obtained a value of 1.12V. This means that the as received Inconel 718 (solution treated) is more susceptible to pitting corrosion than the double aged. This is probably related to the largest area of grain boundaries per unit volume on the as received condition. In the double aged the secondary phases phases are redistributed, which may have reduced the ability of passivating film formation. Taking in account the elements aluminum and chrome, the formation of chromium carbide ($Cr_{23}C_6$) and his migration to the grain boundary, which occurs preferentially when heating or cooling is slow in the temperature range 425-815°C, may be related to the lower susceptibility to pitting corrosion of the aged sample. However, at least at the initiation of the pitting corrosion, the rate of pitting formation, current densities associated to the pitting process, are smaller in the double aged alloy than in the as receive Inconel 718. The optical images (Figure 4) of Inconel 718 before corrosion tests and obtained from the samples submited to chronoamperometric tests at 1.18V

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for as received condition and 1.12V for double aged condition details the pitting corrosion formation.

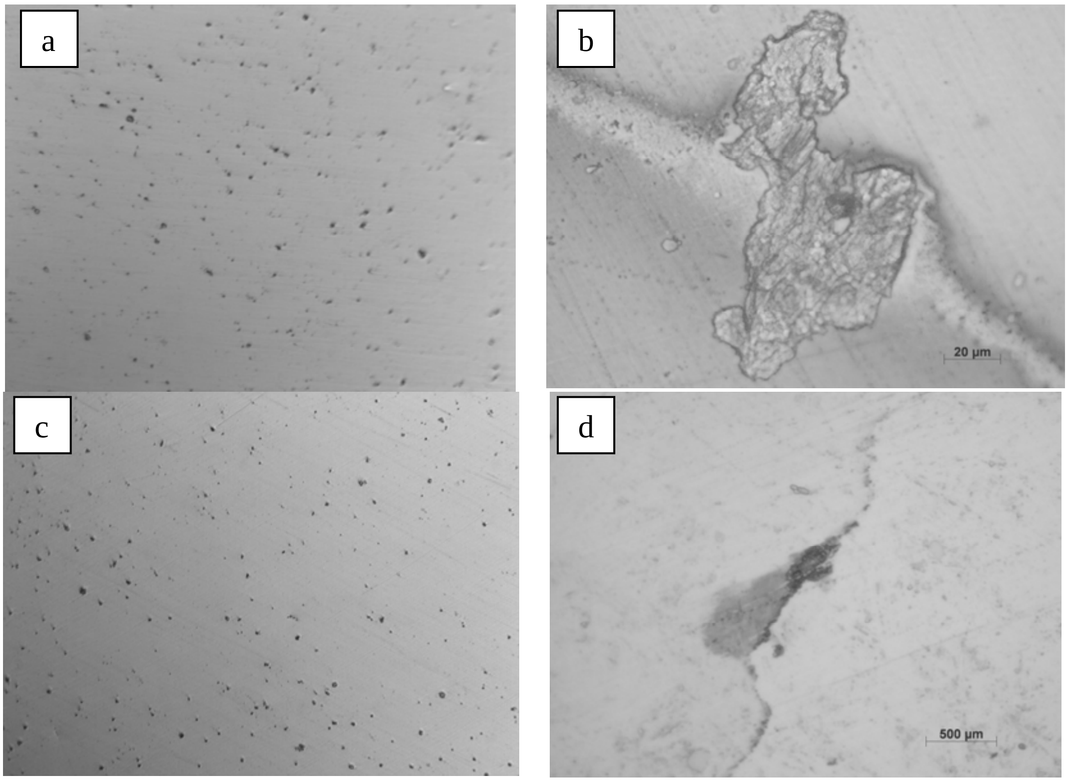

Figure 4. Images of Inconel 718: a) As received and c) Double aged. Detail of pitting corrosion on: b) as received condition and d) double aged condition.

4 CONCLUSIONS

From the presented results, it can be concluded that:

- the procedures suggested in standard ASTM F746-04[4] and Yashiro et al.[3] and ASTM F746-04[4] are not adequate to obtain the pitting corrosion potenteial of the Inconel 718 in chloride containing aqueous solution, probably due to the elevated corrosion resistance of this alloy;
- the as received Inconel 718 has a pitting corrosion potential of 1.18V, whereas the double aged condition has a potential of 1.12V. The lower pitting corrosion resistance of the double aged condition is probably due to the lower capacity of passivation film formation and the precipitation of $Cr_{23}C_6$ along the grain boundaries (sensitization).

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