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Corrosion Behaviour of Injection Moulded 316L and 17-4PH Stainless Steels in a Sodium Chloride Solution

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Abstract: In this study, the corrosion resistance of 316L and 17-4PH PIM stainless steel has been investigated. The corrosion performance was analysed by ASTM B-117 salt spray tests, weight loss measurements and potentiodynamic polarisation tests carried out in 3% NaCl. Salt spray and weight loss results indicated that both steels had high corrosion resistance in sodium chloride. No signs of corrosion were seen on the surfaces of these steels, even after 30 days of exposure to a salt spray test or after 33 days immersed in 3% NaCl solution. The polarisation curves revealed similar corrosion behaviour for both steels, and low corrosion rates at the corrosion potential. However, a tendency to pitting was observed.

Introduction

One of the main characteristics of stainless steels is their corrosion resistance [1]. Sintered stainless steels, however, present inferior corrosion resistance compared to similar materials produced by conventional metallurgy, mainly due to their inherent residual open porosity [2-7]. Excessive open porosity increases the area exposed to a corrosive environment and, consequently, induces crevice corrosion. The formation of concentration cells in the interior of pores reduces the passivity of sintered materials [8-10]. Further confirmation of this fact has been provided by Otero *et. al.* upon studying 316L and 304L steels in organic acids [11]. Klar [12] has reported that the addition of molybdenum to 316L steel improves both pit and crevice corrosion resistance of the alloy. Numerous aspects such as porosity, sintering atmosphere, and powder homogeneity can determine the corrosion rate of the material. Injection moulding has been applied to powdered materials as an alternative route to manufacture corrosion-resistant sintered components [13,14].

The corrosion behaviour of PIM 316L and 17-4PH steels produced by powder injection moulding has been investigated in synthetic saliva [15], and potential applications in orthodontic apparatus is foreseen[13].

This investigation provides an attempt to assess the potential application of these PIM steels in marine environments. The steels under investigation depicted residual porosity, which could affect their corrosion behaviour. The corrosion resistance of both AISI 316L and 17-4PH PIM steels was analysed in a simulated marine atmosphere by conventional salt spray test (ASTM B-117) [16]. Gravimetric and potentiodynamic polarisation tests in 3 % NaCl solution were also carried out.

Materials and methods

Steels

316-L and 17-4PH injected steel samples were supplied by Steelinject LUPATECH, (Caxias do Sul, Brazil). The average particle size of the starting powders was 6.6 and 9.2 μm, respectively. The chemical compositions of the materials are summarised in Table 1. Both 316L and 17-4PH samples were pre-sintered at 980 °C for 1 hour under H_2. The former was then sintered at 1300°C for 4 hours in a reducing atmosphere of argon/hydrogen and the latter at 1350 °C in vacuum, argon/hydrogen for 3 hours. The densities of the sintered materials were 7.59 and 7.61 g.cm^{-3}, yielding 4% and 3% porosity, respectively. The surfaces of the specimens were ground on silicon carbide paper of grit size varying from #200 to #1000. Subsequently, they were rinsed in water and alcohol, dried under hot air, and stored until tested.

Table 1: Chemical composition (in wt %) of 316L and 17-4PH injected stainless steel.

Stainless Steel	C	Si	Mn	P	S	Ni	Cr	Mo	Cu
316L	0.013	0.80	0.20	0.031	0.003	13.5	16.40	2.2	-
17-4PH	0.05	0.76	0.25	0.026	0.020	4.0	16.70	0.30	3.95

Gravimetric Analysis

Gravimetric tests were performed immersing specimens of both classes of steel in a solution containing 3 % NaCl. After a period of time, the specimen was removed from the solution, immersed in an ultrasonic bath with alcohol, dried and finally weighed. The total length of such tests was 33 days.

Potentiodynamic Polarisation Tests

Potentiodynamic polarisation tests were carried out in the same type of solution used for the gravimetric tests, i.e., 3 % NaCl. The specimens were immersed in the test solution for an initial period of 1 hour necessary to stabilise its potential. Polarisation was then carried out using an EG&G PARC 273A potentiostat interfaced with a microcomputer via a GPIB interface. A three-electrode system was employed. A saturated calomel electrode (SCE) was used as the reference electrode, and a graphite rod as the counter electrode. The specimen was polarised in the range from –100 mV (vs. open circuit potential) to 1.6 V. The scan rate was set to 0.8 mV/s.

SEM Surface Analysis

The surface of the specimens was analysed after the polarisation tests by scanning electron microscopy (SEM) using a Phillips XL-30 instrument.

Salt Spray Tests

A series of specimens were also submitted to salt spray tests according to ASTM B-117 guidelines [16,17], for a period of 700 hours.

Results and discussion

Gravimetric Tests

The results of the gravimetric test are shown in Fig. 1. The corrosion rates estimated from the data were invariably below 0.5 mg.dm^{-2}, showing that both steels presented very low corrosion rates in the 3% NaCl solution. Fig. 2 shows specimens immersed for 33 days in NaCl solution. After that period, the surface of the specimen still retained a bright appearance, suggesting the passivation of the steel in NaCl. Such a solution is considered to be fairly aggressive and the low corrosion rates of the tested specimens demonstrate the high corrosion resistance of the steel to a marine atmosphere.

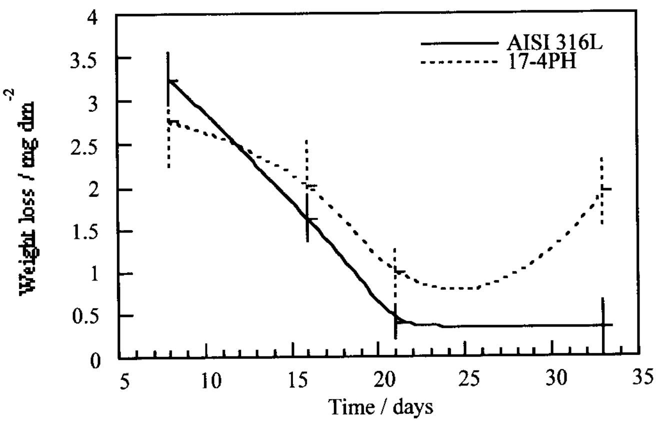
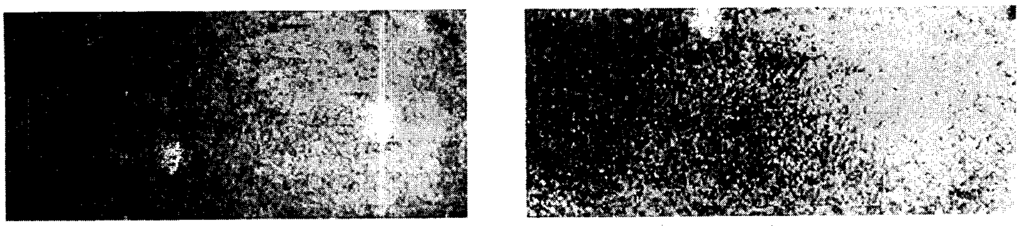


Fig. 1 - Weight loss of 316L and 17-4PH PIM steels in 3% NaCl solution.



(a) (b)

Fig. 2 - AISI 316L and 17-4PH steel specimens after 33 days immersed in 3 % NaCl solution.

Open Circuit Potential vs. Time

The open circuit potential (OCP) was measured as a function of time in 3 % NaCl electrolyte. OCP *vs.* time behaviour of injection moulded 316L and 17-4PH was similar to what has been observed for chromium, nickel and stainless steel, depicting shifts to nobler regions and indicating passivation[18-20]. In addition, a slight potential oscillation was observed, after a certain potential level, suggesting an aggressive action of chloride ions towards the passivating layer.

Potentiodynamic Polarisation Curves

The potentiodynamic polarisation curves of 316L and 17-4PH steels in NaCl solution are presented in Fig. 3. The corrosion rates at the corrosion potential (i_{corr}) of both steels were less than 1 $\mu A/cm^2$, further confirming the high corrosion resistance of both steels in chloride medium. The anodic polarisation curve however indicated a behaviour typical of a metal in the active region (low overpotentials caused an increase in the corrosion rates), supporting the aggressive action of chloride ions towards the steels and a tendency to pitting.

An illustration of the surface of a specimen subjected to a potentiodynamic polarisation scan up to 1.6V in 3% NaCl solution is shown in Fig. 4 a and b. As it can be seen, corrosion took place in small areas of the surface, originating pits. The number of pits significantly increased, and excessive corrosion took place mainly around the grains [18]. Stainless steels contain numerous inclusions, secondary phases, and regions of compositional heterogeneity, and there have been a great number of results that relate pitting onset to structural surface heterogeneity, particularly inclusions[1]. Pit propagation is thought to involve metal dissolution and the maintenance of a high degree of acidity at the bottom of the pits by the hydrolysis of dissolved metal ions [1].

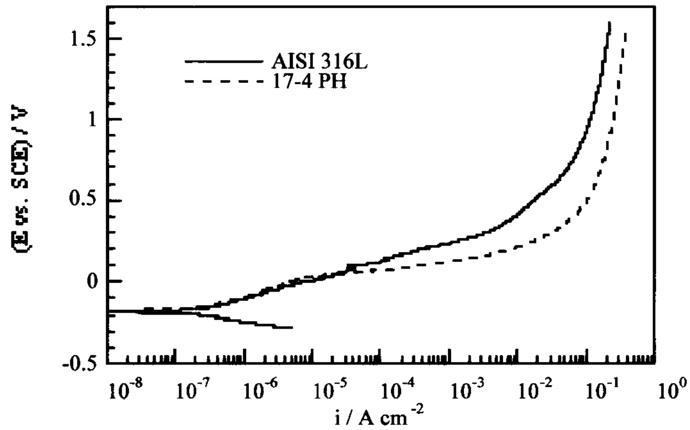
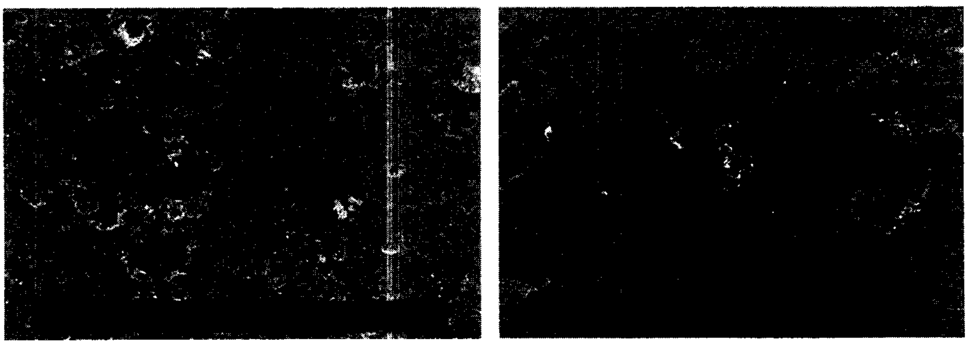


Fig. 3 - Polarisation curves of 316L and 17-4PH steels in 3 % NaCl solution.

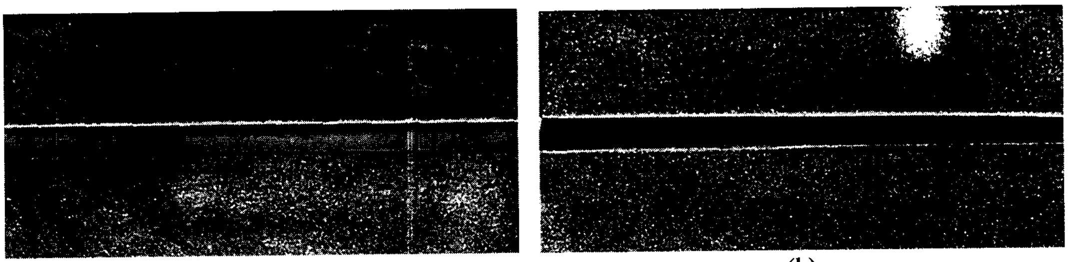


(a) (b)

Fig. 4 - SEM image of (a) 17-4PH and (b) 316L steels after polarisation test.

Salt spray tests

The surface of the steels after 700 hours of exposure to the salt spray is shown in Fig. 5.



(a) (b)

Fig. 5 - Specimens of (a) 316 L and (b) 17-4PH, after 700 hours of exposure to salt spray.

Specimens of both steels showed no signs of corrosion after 700 hours of salt spray testing. This result indicates a high resistance of both steels to the test environment and confirmed the results obtained by the other techniques indicating that both materials are potential candidates for use in typical marine environments.

Conclusions

The results obtained showed that both tested PIM steels (AISI 316L and 17-4PH) are promising as materials for applications where they are exposed to marine atmosphere. A tendency to pitting was however found for both steels at low overpotentials.

References

[1] A. J. Sedriks. *Corrosion of stainless steels*. John Wiley & Sons, New York, (1979).
[2] P. C. Borges, N. C. Pereira, C. V. Franco and A .N. Klein. Advances in Powder Metallurgy & Particulate Materials. 2 (1994) p. 61.
[3] A. V. C. Sobral, A. M. Maliska, G. Tosi, J.L.R. Muzart, A N. Klein and C. V. Franco. Advances in Powder Metallurgy & Particulate Materials, 3 (1995) p.11.
[4] N. C. Pereira, F. G. Mittelstadt, A Spinelli, C. V. Franco, A. M. Maliska, A N. Klein, and J. L. R. Muzart. J. Materials Science, 30 (1995) p. 4817.
[5] A. V. C. Sobral. Electrochemical and Metalographic Characterization of Nitrided Sintered Steels 1996. *Master Thesis*, Chemistry Department, Federal University of Santa Catarina, SC, Brazil. (In Portuguese)
[6] A.V.C. Sobral, A. C. B. Parente, J. L. R. Muzart and C. V. Franco. Surface & Coatings Technology, 92 (1997) p. 10.
[7] E. Maahn, S. K. Jensen, R. M. Larsen, T. Mathiesen. Advances in Powder Metallurgy and Particulate Materials, 7 (1994) p. 253.
[8] T. Mathiesen and E. Maahn. Advances in Powder Metallurgy and Particulate Materials, 3 (1995) p. 45.
[9] L. Fedrizzi, F. Deflorian, A. Tiziani, I. Cristofolini, A. Molinari. Advances in Powder Metallurgy and Particulate Materials, 7 (1994) p. 273.
[10] A. Tremblay and R. Angers. Advances in Powder Metallurgy and Particulate Materials, 7 (1995) p. 225
[11] E. Otero, A. Pardo, M. V. Utrilla, F. J. Pérez and C. Merino, Corrosion Science 39, (1997) p. 453.

[12] E. Klar and P. K. Samal. Advances in Powder Metallurgy and Particulate Materials, 11 (1995) p. 17.
[13] R. M. German. *Powder Metallurgy Science*, 2nd Ed., (1994).
[14] M. K. Bulger, A. R. Erickson. Advances in Powder Metallurgy and Particulate Materials, 4 (1994) p. 197.
[15] A.V.C. Sobral, W. Ristow Jr., C. V. Franco, 3rd NACE Latin American Region Corrosion Congress, (1998) Paper No.S17-15 (CD).
[16] ASTM Standard B117, Method of Salt-Spray (Fog) Testing, Annual Book of ASTM Standards, Vol. 03.01 (Philadelphia, PA: ASTM).
[17] M. Stratmann, K. Bohnenkamp, T. Ramchandran. Corrosion Science, 27 (1987) p. 905.
[18] D. A Jones. Principles and Prevention of Corrosion. Macmillan, 1991, p. 18.
[19] ASM Metals Handbook Series, Vol. 13, Corrosion, (1992).
[20] H. S. Isaacs. Corrosion Science, 29 (1989) p. 313.

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