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THE CORROSION BEHAVIOUR OF FERRITIC STAINLESS STEELS IN ALKALINE SOLUTIONS

KOROZIJSKO VEDENJE FERITNIH NERJAVNIH JEKEL V ALKALNIH RAZTOPINAH

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The corrosion resistances of X6Cr17 and X2CrTi17 ferritic stainless steels and cold-rolled, low-carbon steel, as well as circular and transversal welds of X6Cr17 ferritic stainless steel, were investigated in a non-phosphate detergent with a solution pH of 10.5 and at a temperature of 60 °C. The second investigated solution contained the non-phosphate detergent and sodium perborate tetrahydrate at pH 11 and was at a temperature of 90 °C. The potentiodynamic measurements showed that the corrosion resistance decreased from X2CrTi17 and X6Cr17 to the welded specimens and the cold-rolled, low-carbon steel in non-phosphate detergent at the lower temperature. At the elevated temperature and with the addition of sodium perborate tetrahydrate the corrosion stability of all the investigated materials decreased significantly.

Keywords: ferritic stainless steel, potentiodynamic, alkaline solution, corrosion

Preučevali smo korozijsko odpornost vzorcev X6Cr17, X2CrTi17 feritnih nerjavnih jekel, hladno valjanega maloogljičnega jekla in krožnega ter prečnega zvara X6Cr17 feritnega nerjavnega jekla v raztopini nefosfatnega detergenta pri pH 10,5 in temperaturi 60 °C. Druga preiskovana raztopina je vsebovala nefosfatni detergent in natrijev perborat tetrahidrat pri pH 11 in temperaturi 90 °C. Rezultati potenciodinamskih meritev so pokazali, da sta korozijsko najbolj obstojna materiala X2CrTi17 in X6Cr17, manj pa obe vrsti zvarov in hladno valjano malooglji̇čno jeklo. Pri povišani temperaturi in z dodatkom natrijevega perborata tetrahidrata se je korozijska odpornost vseh petih vzorcev izrazito zmanjšala.

Ključne besede: feritna nerjavna jekla, potenciodinamske, alkalna raztopina, korozija

1 INTRODUCTION

Ferritic steels with about 17 % Cr (e.g., X6Cr17, AISI 430, and EN 1.4016) are of interest as they are some of the most widely used stainless engineering materials and offer an attractive alternative to the more expensive austenitic stainless-steel grades.[1] X6Cr17 is a ferritic, straight chromium, non-hardenable grade, combining good corrosion resistance and formability characteristics with useful mechanical properties.[1] It has a good resistance to a wide variety of corrosive media, including nitric acid and some organic acids. It attains its maximum corrosion resistance in the highly polished or buffed condition. In general, its resistance to pitting and crevice corrosion resistance is close to that of the steel grade 304.[2] The stress-corrosion cracking resistance of Grade X6Cr17 is very high, as it is for all ferritic grades.[3,4] Typical applications for the X6Cr17 grade include the linings for dish washers, refrigerator-cabinet panels, automotive trim, lashing wire, element supports, stove trim rings, fasteners and chimney liners.[1]

The ferritic stainless steel X2CrTi17 stabilised with titanium has a very good resistance to intergranular corrosion.[5] Furthermore, titanium also binds sulphur and leads to improved pitting corrosion. All ferritic stainless steels are also resistant to stress-corrosion cracking and have a good corrosion resistance to mineral acids, cold dilute organic acids and cold oxidizing and alkaline salt solutions, to atmospheric corrosion, to high-temperature oxidation and to hot water.[5] Stabilisation with titanium results in a good toughness and ductility for the welds. The corrosion resistance of the welds is similar to that of the base metal. The typical applications of this grade are in domestic appliances, such as the tubs and drums of washing machines.

The aim of the present study was to evaluate the corrosion resistance of X2CrTi17 and X6Cr17 ferritic stainless steels as well as circular and transversal welds of X6Cr17 ferritic stainless steel in alkaline solutions using potentiodynamic measurements in order to establish an appropriate substitution of X2CrTi17 with X6Cr17 for washing machines. A cold-rolled, low-carbon steel was also investigated.

2 EXPERIMENTAL

The nominal values of the chemical composition of the investigated materials are shown in **Table 1**.

The experiments were carried out in two solutions. The first solution consisted of 10 g/L 2508 SDC IEC non-phosphate detergent, allowed for use in the international standard "ISO 6330:2000 Domestic Washing and Drying Procedures for Textile Testing" and contains fluorescent brightening agents, with a pH of 10.5 at a temperature of 60 °C.

Table 1: The nominal values of chemical composition of X6Cr17, X2CrTi17 ferritic stainless steels and cold rolled low-carbon steel (*w*/%)
Tabela 1: Nominalne vrednosti kemijske sestave X6Cr17, X2CrTi17 feritnih nerjavnih jekel in hladno valjanega maloogljičnega jekla (*w*/%)

	C	Si	Mn	Cr	S	P	N	Ti
X6Cr17	0.12 max	1.00 max	1.00 max	14–18	0.03 max	0.040 max	–	–
X2CrTi17	0.025 max	0.50 max	0.50 max	16–18	0.015 max	0.040 max	0.015 max	0.35 max
DC01 EN10130	0.12 max	–	0.60 max	–	0.045 max	0.045 max	–	–

The second solution was prepared by the dissolution of 8 g of 2508 SDC IEC non-phosphate detergent and 2 g of sodium perborate tetrahydrate per litre of H_2O at pH 11 and a temperature of 90 °C. Sodium perborate tetrahydrate is a reagent allowed in the international standards "ISO 105 C06, C08 and C09" and "ISO 6330: 2000". It acts as a bleaching agent and is incorporated into the latest standards to replicate modern commercial laundry products.

The test specimens were cut into discs of 15 mm diameter. The specimens were then embedded in a Teflon PAR holder and employed as a working electrode. The reference electrode was a saturated calomel electrode (SCE, 0.242 V vs. SHE) and the counter electrode was a high-purity graphite rod. All the potentials described in the text are stated with respect to SCE.

The potentiodynamic measurements were recorded using an EG&G PAR PC-controlled potentiostat/galvanostat Model 263 with M252 and Softcorr computer programs. For the potentiodynamic measurements the specimens were immersed in the solution 1 hour prior to the measurement in order to stabilize the surface at the open-circuit potential. The potentiodynamic curves were recorded starting from a potential that was 250 mV more negative than the open-circuit potential. The potential was then increased using a scan rate of 1 mV s^{-1}, until the transpassive region was reached.

3 RESULTS AND DISCUSSION

The corrosion-current density (i_{corr}) and the potential at zero current ($E(I = 0)$) values were calculated from linear polarization measurements and Tafel plots using the equation:

$$R_p = \beta_a \beta_c / (2.3\ I_{corr}\ (\beta_a + \beta_c))$$

The corrosion current, I_{corr}, is calculated from R_p, the least-squares slope, and the Tafel constants, β_a and β_c, of the 100 mV $decade^{-1}$. The value of $E(I = 0)$ is calculated from the least-squares intercept.

The potentiodynamic behaviours of the investigated materials in two testing solutions are shown in **Figures 1 and 2**, accompanied by calculated values of the corrosion rates, the corrosion-current densities (i_{corr}), the potentials at zero current ($E(I = 0)$) and the polarisation resistances (R_p) (**Tables 2 and 3**). The differences in the alloys' composition affected the polarisation and the passivation behaviours of the tested materials.

Figure 1 compares the potentiodynamic polarisation curves for the X6Cr17 and X2CrTi17 ferritic stainless steels and the cold-rolled, low-carbon steel as well as circular and transversal welds of X6Cr17 ferritic stainless steel in the phosphate detergent at 60 °C. After 1 h of stabilization at the open-circuit potential, the $E(I = 0)$ for X6Cr17 in the non-phosphate detergent at 60 °C was approximately –0.15 V. Following the Tafel region, the alloy exhibited a semi-passive behaviour with three active-passive transition zones. The breakdown potential (E_b) for the X6Cr17 was approximately 0.75 V. For the case of X2CrTi17, the $E(I = 0)$ was approximately equal to –0.24 V. The range of passivation was similar to that for the X6Cr17 specimen without the active-passive

Table 2: Calculated values of corrosion rates (v_{corr}), corrosion current densities (i_{corr}), potentials at zero current ($E(I = 0)$) and polarisation resistances (R_p) for X6Cr17, X2CrTi17 ferritic stainless steels and cold rolled low-carbon steel as well as circular and transversal welds of X6Cr17 ferritic stainless steel in non phosphate detergent at 60 °C.
Tabela 2: Izračunane vrednosti korozijske hitrosti, gostote korozijskega toka, potenciala pri ničelnem toku in polarizacijske upornosti za vzorce X6Cr17, X2CrTi17 feritnih nerjavnih jekel hladno valjanega maloogljičnega jekla in krožnega ter prečnega zvara X6Cr17 feritnega nerjavnega jekla v raztopini nefosfatnega detergenta pri 60 °C

Sample	v_{corr} / (mm/year)	$E(I = 0)$ /mV	i_{corr} / (μA/cm^2)	R_p /kΩ
X6Cr17	0.0013	−151.3	0.120	277.0
X6Cr17 (circular weld)	0.036	−242.1	3.282	13.16
X6Cr17 (transversal weld)	0.015	−281.5	1.399	27.26
DC01 EN10130	0.059	−340.5	6.132	5.382
X2CrTi17	0.0013	−240.8	0.116	310.5

Table 3: Calculated values of corrosion rates, corrosion current densities (i_{corr}), potentials at zero current ($E(I = 0)$) and polarisation resistances (R_p) for X6Cr17, X2CrTi17 ferritic stainless steels and cold rolled low-carbon steel as well as circular and transversal welds of X6Cr17 ferritic stainless steel in non phosphate detergent with the addition of sodium perborate tetrahydrate at 90 °C.
Tabela 3: Izračunane vrednosti korozijske hitrosti, gostote korozijskega toka, potenciala pri ničelnem toku in polarizacijske upornosti za vzorce X6Cr17, X2CrTi17 feritnih nerjavnih jekel hladno valjanega maloogljičnega jekla in krožnega ter prečnega zvara X6Cr17 feritnega nerjavnega jekla v raztopini nefosfatnega detergenta z dodatkom natrijevega perborata tetrahidrata pri 90 °C

Sample	v_{corr} / (mm/year)	$E(I = 0)$ /mV	i_{corr} / (μA/cm^2)	R_p /kΩ
X6Cr17	0.059	−21.62	5.442	6.063
X6Cr17 (circular weld)	0.411	−40.08	37.77	1.137
X6Cr17 (transversal weld)	0.351	−78.87	32.22	0.781
DC01 EN10130	8.167	−434.4	847.4	0.0565
X2CrTi17	0.049	−4.851	4.568	7.700

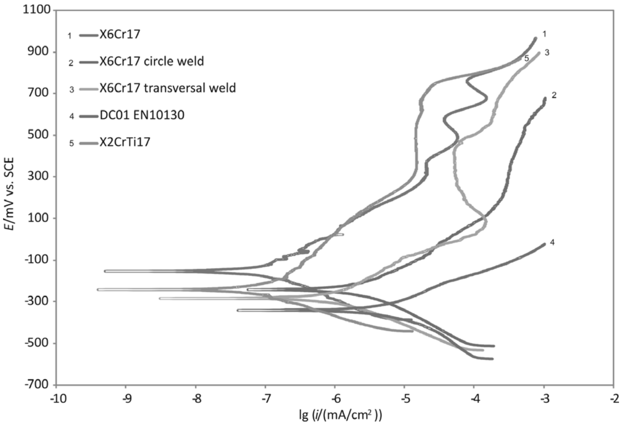

Figure 1: Potentiodynamic polarisation curves for X6Cr17, X2CrTi17 ferritic stainless steels and cold rolled low-carbon steel as well as circular and transversal welds of X6Cr17 ferritic stainless steel in non phosphate detergent at 60 °C.

Slika 1: Potenciodinamske krivulje vzorcev X6Cr17, X2CrTi17 feritnih nerjavnih jekel hladno valjanega malooglji čnega jekla in krožnega ter prečnega zvara X6Cr17 feritnega nerjavnega jekla v raztopini nefosfatnega detergenta pri 60 °C

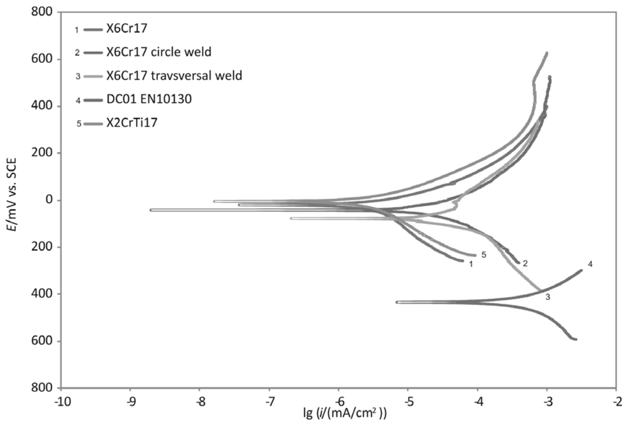

Figure 2: Potentiodynamic polarisation curves for X6Cr17, X2CrTi17 ferritic stainless steels and cold rolled low-carbon steel as well as circular and transversal welds of X6Cr17 ferritic stainless steel in non phosphate detergent with the addition of sodium perborate tetrahydrate at 90 °C.

Slika 2: Potenciodinamske krivulje vzorcev X6Cr17, X2CrTi17 feritnih nerjavnih jekel hladno valjanega malooglji čnega jekla in krožnega ter prečnega zvara X6Cr17 feritnega nerjavnega jekla v raztopini nefosfatnega detergenta z dodatkom natrijevega perborata tetrahidrata pri 90 °C

transition zones and an E_b of 0.75 V. The corrosion-current densities in the passive range had lower values for the X2CrTi17 specimen. The $E(I = 0)$ values for the circular and transversal welds of X6Cr17 ferritic stainless steel in the non-phosphate detergent at 60 °C were –0.24 V and –0.28 V, respectively. The corrosion-current densities for both welded specimens increased significantly in comparison to the non-welded sample. The cold-rolled, low-carbon steel was the least corrosion resistant of all the investigated samples, with an $E(I = 0)$ value of –0.34 V and a corrosion-current density of 6 μA/cm^2. The calculation of the polarisation resistance (R_p) showed that the corrosion stability of the X2CrTi17 specimen was the greatest of all the tested materials, with an R_p value of approximately 300 kΩ. The second most stable specimen was the steel X6Cr17 with an R_p value of approximately 280 kΩ. The welded specimens and the cold-rolled, low-carbon steel exhibited a significant decrease in R_p values, indicating a lower corrosion resistance of these specimens compared to the steels X6Cr17 and X2CrTi17 (**Table 2**).

In **Figure 2** the potentiodynamic polarisation curves for the X6Cr17 and X2CrTi17 ferritic stainless steels, and the cold-rolled, low-carbon steel, circular and transversal welds of X6Cr17 ferritic stainless steel in the non-phosphate detergent with the addition of sodium perborate tetrahydrate at 90 °C are shown. The corrosion resistance of all the investigated samples decreased considerably, compared to the results in the non-phosphate detergent at lower temperatures. The steels X2CrTi17 and X6Cr17 exhibited improved corrosion characteristics compared to the other three samples, although the difference with the welded specimens was not so pronounced as in the first solution due to the aggressiveness of the second solution (**Table 3**). The corrosion stability of the cold-rolled, low-carbon steel decreased a great deal with the addition of sodium perborate tetrahydrate and the higher temperature (**Table 3**).

4 CONCLUSION

The present electrochemical study was conducted in order to determine the corrosion performance of different ferritic stainless steels in a specific alkaline environment; the influence of welding and the chemical composition of the selected materials on the corrosion characteristics was evaluated, also.

The potentiodynamic measurements were performed with the investigated steels and welds in a non-phosphate detergent at 60 °C and with the addition of sodium perborate tetrahydrate at 90 °C. The results showed the superior corrosion stability of the X2CrTi17 and X6Cr17 ferritic stainless steels in comparison to the welded X6Cr17 ferritic stainless steel and the cold-rolled, low-carbon steel at the lower temperature. The corrosion resistance of all the investigated materials decreased significantly at the elevated temperature and with the addition of sodium perborate tetrahydrate. The X2CrTi17 and X6Cr17 ferritic stainless steels showed comparable electrochemical characteristics, while the corrosion stability of the circular and transversal welds of the X6Cr17 ferritic stainless steel was similar. The resistance of the cold-rolled, low-carbon steel to corrosion in the alkaline solution was significantly diminished in comparison with the other investigated materials.

The results of the present study indicate that the electrochemical characteristics of the X6Cr17 and

X2CrTi17 ferritic stainless steels in alkaline media at elevated temperatures are similar. This allows the substitution of X2CrTi17 with X6Cr17 ferritic stainless steel in the fabrication of washing machines.

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