

UNS N08935 - a new alloy for seawater applications

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ABSTRACT

UNS N08935, is a new alloy with composition 35Ni–30Fe–27Cr–6.5Mo–0.28N, with a very high localized corrosion resistance. Previous results have shown that the alloy has a critical pitting temperature (CPT) above 100°C in the modified electrochemical ASTM G150 method in 3M MgCl₂ solution. The results indicate good performance in seawater environments.

In the process industry seawater is commonly used, when available, to cool process fluids. Natural seawater at ambient temperature is very corrosive due to for instance microbial activity.

This paper presents pitting- and crevice corrosion results for UNS N08935 and UNS N06625 from three months exposure in natural seawater at 30°C and in chlorinated seawater at 45°C, 50°C and 80°C. The results indicate that UNS N08935 could be a stainless steel solution in seawater applications where more expensive nickel base alloys are used today.

Key words: UNS N08935, Pitting Corrosion, Crevice Corrosion, Seawater, Chlorination, Stainless Steels, CRA, UNS N06625, Nickel Base Alloys

INTRODUCTION

UNS N08935, Sanicro®35[†], is a new alloy with composition 35Ni–30Fe–27Cr–6.5Mo–0.28N, with a high pitting resistance equivalent number (PREN) of 52. The PRE-number is calculated according to equation 1, with the chemical composition in weight-% of elements important for the pitting corrosion resistance.

$$\text{PREN} = [\text{Cr}\%] + 3.3 \times [\text{Mo}\%] + 16 \times [\text{N}\%] \quad (1)$$

[†] Trade name

Previous results have shown the alloy to have a critical pitting temperature (CPT) above 100°C in the modified electrochemical ASTM⁽¹⁾ G150 method in 3M MgCl₂ solution.^{1,2,3} These results imply good performance in seawater environments.

In the process industry seawater is commonly used, when available, to cool process fluids. Natural seawater at ambient temperature is very corrosive due to for instance the high chloride concentration in combination with microbial activity.

The open-circuit potential (OCP) is an electrochemical parameter commonly used to assess the risk of corrosion for alloys. The potential of an alloy in seawater is generally affected by environmental factors such as dissolved oxygen, chlorination, temperature, flow rate, biological activity. Furthermore, corrosion products and other changes in surface composition can also affect the potential.^{4,5,6,7}

It is well known that a biofilm often forms on a stainless steel surface in natural seawater at certain temperatures. This results in a potential ennoblement of approximately +300 mV versus standard saturated calomel electrode (SCE). The incubation period before ennoblement and the magnitude of the ennoblement depends on the temperature and the exact biological conditions of the used seawater. The increase in potential makes it more severe and increase the risk for localized corrosion attacks. The biofilm additionally leads to better efficiency of cathodic reduction of oxygen on the surface which can lead to accelerated corrosion propagation.⁵

However, chlorination of the seawater is widely used to limit any microbial activity; that also makes the environment aggressive. Chlorination oxidizes and increases the potential to approximately +600 mV/SCE for stainless steels and leads to higher susceptibility to localized corrosion. To summarize this, Figure 1 presents the OCP schematically for stainless steels in seawater in varied conditions.⁴ Nickel base alloys have a different OCP appearance in chlorinated seawater, where it stays at around +300 mV/SCE depending on chlorine level.^{5,6}

UNS N08935 is a stainless steel with relatively high nickel content and that makes it interesting to explore the performance in chlorinated seawater. UNS N06625 is a nickel base alloy with good pitting corrosion resistance in seawater, however it has limitations when it comes to severe crevices.⁶ UNS N06625 has been tested in this study as a reference. The aim with this study was to test the localized corrosion resistance of UNS N08935 in natural and chlorinated seawater and compare it with a well-known nickel base alloy, UNS N06625, that is widely used in seawater applications.

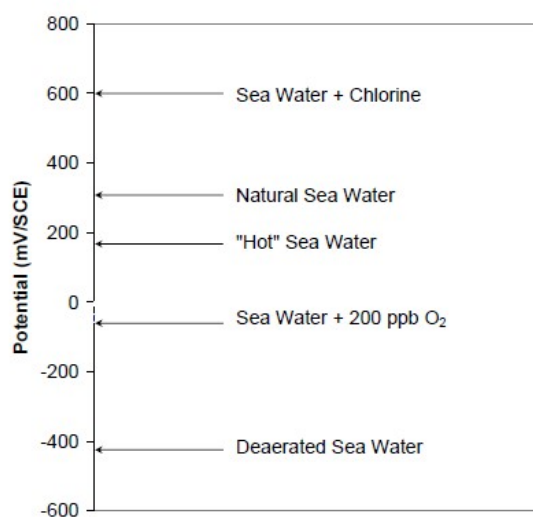


Figure 1: Potentials obtained with high alloy stainless steels in seawater⁴

⁽¹⁾ ASTM International (ASTM), 100 Barr Harbor DR. West Conshohocken, PA 19428-2959

EXPERIMENTAL PROCEDURE

Materials

Material from full-scale heats have been used in the seawater testing of UNS N08935. The heats have been produced by melting in an electric arc furnace followed by Argon Oxygen Decarburization (AOD) refining. The chemical composition of the tested materials is presented in Table 1. Flat specimens were prepared from Ø138 mm bar material and machined to 50x50x15 mm for pitting specimens and 100x100x15 mm with a Ø7 mm hole in the center for the crevice assembly. All specimens had a 3 mm hole in one corner for mounting. The specimen surfaces were machined with 120 grit paper prior to testing. 150 mm long seamless tube specimens from UNS N08935 with dimension 25.4x2.11 mm with crevice assemblies were also tested in natural seawater. The exposed surfaces were as delivered with cutting surfaces ground with 120 grit paper.

Table 1
Chemical composition of tested material

UNS	Product	C	Si	Mn	Cr	Ni	Mo	Cu	N	Nb	PREN
N08935	Bar	0.017	0.20	0.64	27.0	35.1	6.3	0.16	0.31	-	53
N06625	Bar	0.018	0.06	0.09	21.3	63.3	8.3	0.04	-	3.35	49
N08935	Tube	0.015	0.18	0.77	26.9	34.8	6.3	0.20	0.29	-	52

Crevice assembly

Standard crevice assemblies for plates were used according to ISO⁽²⁾ 18070 to test the flat specimens. The crevice formers were made of polyvinylidene fluoride (PVDF) and all fasteners were made of titanium grade 2 and electrically isolated from the tested specimen. Disc springs were used to keep a measurable and constant pressure between the crevice formers and the specimen. The applied crevice force was chosen according to ISO 18070, where the crevice former should be tightened to the specimens with a force of about 900N (i. e. pressure of about 3 N/mm²), which corresponds to a torque of 3 Nm on the used fasteners.^{7,8} A schematic representation and a picture of the crevice assembly for the flat specimens are shown to the left in Figure 2.⁹

The crevice assembly for the tube specimens, see picture to the right in Figure 2, is a newly developed design to get a more uniform distribution of the crevice force and to be more comparable to flat specimens.⁹ The same crevice pressure of 3 N/mm² was used.

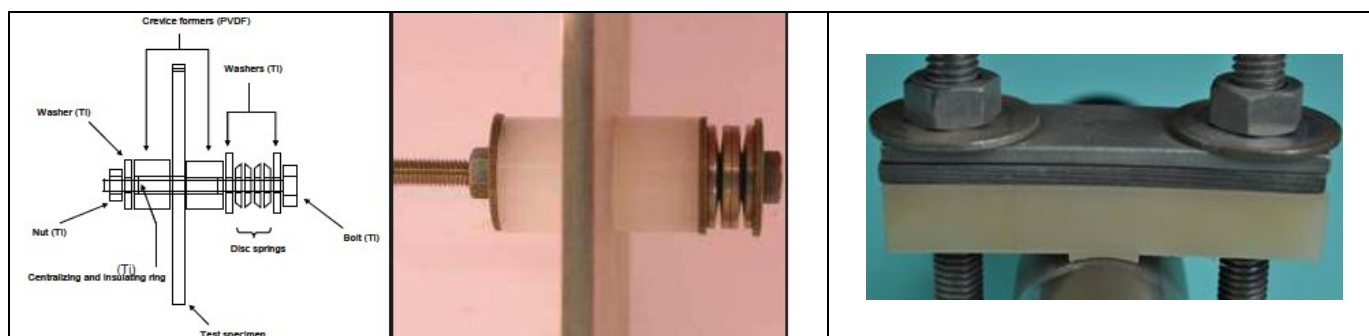


Figure 2: Crevice assembly for plate respective tube specimens⁹

⁽²⁾ ISO (ISO), Ch. De Blandonet 8. CH-1214 Vernier, Geneva, Switzerland

Test conditions

Specimens were exposed for 3 months in seawater tanks with natural seawater pumped directly from the open sea in the bay of Brest (France) from 5 to 10 m under the seawater level, with an average salinity of 35‰. The seawater was heated to the test temperature and the renewal rate of the seawater was about 300 L/day. The heating was performed with regulated titanium heaters in an external container to prevent both a gradient of temperature and a too significant stirring in the inner tank where specimens were exposed. The temperatures were controlled at $\pm 1^\circ\text{C}$. The test matrix with the tested conditions are gathered in Table 2.

For tests involving chlorination, the desired residual chlorine content (0.5 ppm) was obtained with a controlled electrolysis of the seawater in tanks. The chlorine concentration was adjusted by electro-chlorination which consists of producing hypochlorite by electrolysis of the seawater salt. The chlorine concentration was controlled with a regulated current supply and measured every day with a photometer.

The open-circuit potential (OCP) of the exposed specimens (2 duplicates) was continuously measured and recorded with high-impedance ($>10^{11}\Omega$) data loggers adapted for electrochemical measurements. For all measurements, Ag/AgCl reference gel electrodes were used. All the electrodes were weekly calibrated with a standard saturated calomel electrode. All potentials given in this work are versus the saturated calomel electrode (SCE).

Table 2
Test conditions and number of specimens

Condition	Pitting assembly	Crevice assembly
30°C Natural seawater	2 flat N08935, 2 flat N06625	3 flat+3 tube N08935, 3 flat N06625
45°C Chlorinated (0.5 ppm) seawater		3 flat N08935, 3 flat N06625
50°C Chlorinated (0.5 ppm) seawater	2 flat N08935, 2 flat N06625	3 flat N08935, 3 flat N06625
80°C Chlorinated (0.5 ppm) seawater	3 flat N08935, 3 flat N06625	

Evaluation of test

Results are presented with potential curves and pictures of the tested specimens showing the visual appearance after testing. Localized corrosion depth was measured by focalization technique using an optical microscope after removal of corrosion products in 20% nitric acid.

RESULTS & DISCUSSION

Natural seawater testing at 30°C

Temperature of the heated natural seawater was regulated around 30°C throughout the exposure time and the temperature chart in Figure 3 shows an average temperature of $29.4 \pm 0.9^\circ\text{C}$.

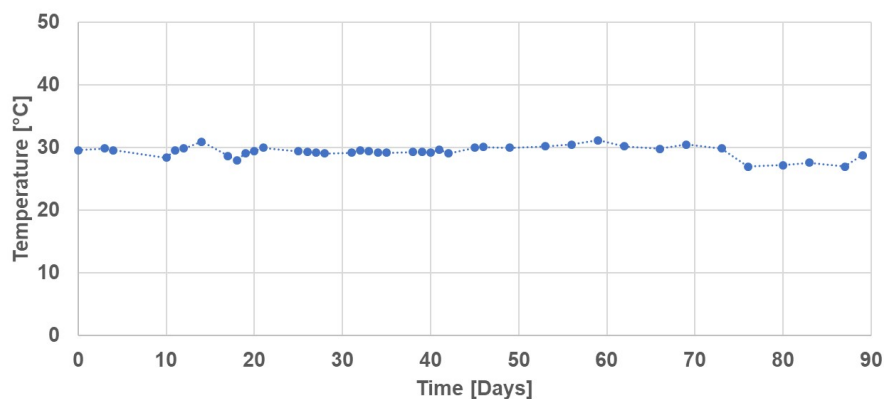


Figure 3: Temperature measurement during 30°C natural seawater testing

Pitting corrosion test

Two specimens of UNS N08935 and UNS N06625 were tested in natural seawater. The open-circuit potential measurements for both alloys are presented in Figure 4 which shows the biofilm ennoblement to 200 mV/SCE after approximately 5 days and stabilized closer to 300 mV/SCE. No signs of corrosion initiation for any of the alloys during the three months exposure. This can also be seen looking at the specimens showed in Figure 5. The results are as expected for alloys with PRE around 50.

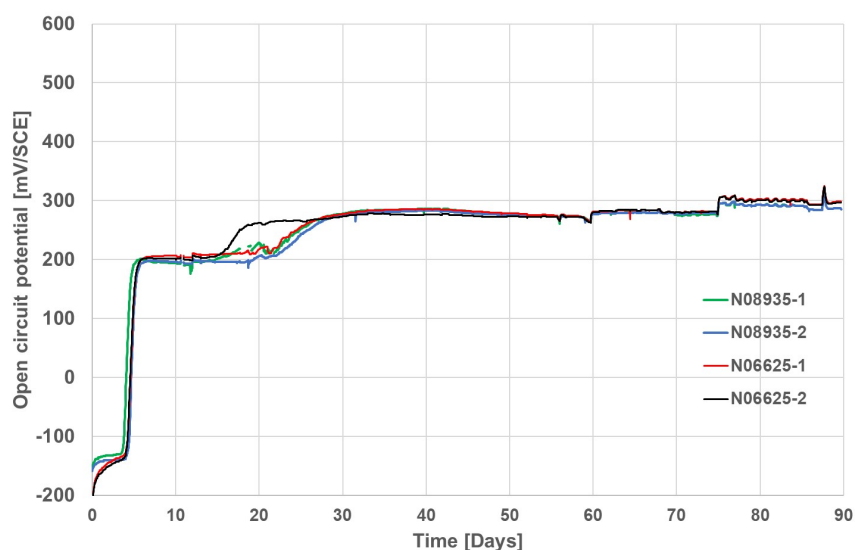


Figure 4: OCP of UNS N08935 and UNS N06625 in pitting configuration in natural seawater at 30°C