

Stress Corrosion Cracking (SCC) and Electrochemical Corrosion Study of Cold Formed Alloy 625 (UNS N06625) In Extremely Low pH and High Chloride Conditions

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ABSTRACT

Corrosion-resistant alloy (CRA) such as alloy 625 (UNS N06625) provides excellent corrosion resistance and chloride stress-corrosion cracking (SCC) resistance than stainless steels in many corrosive environments. Literature shows that under annealed condition alloy 625 is immune to chloride stress-corrosion cracking in high chloride environments and provide excellent localized corrosion resistance in high chloride concentrations. However, the literature shows that when the alloy is heavily cold formed it could become more sensitive to high chloride levels and susceptible to SCC.

In order to understand the sensitivity of alloy 625 under cold-worked conditions, SCC tests were performed on annealed and cold-formed alloy 625 in boiling high concentrations (50,000 ppm and 80,000 ppm) of chlorides (NaCl) and at very low pH (1.0). Electrochemical, linear polarization resistance (LPR) and cyclic potentiodynamic polarization (CPP) scans at 40°C were also performed to study the corrosion and passivation behavior under the above-mentioned chloride concentrations.

The test results show that under cold-formed conditions alloy 625 is not susceptible to SCC in very high concentrations (50,000 ppm and 80,000 ppm) of chlorides and under low pH (1.0) conditions and CPP scans at 40°C demonstrates that under cold-formed condition, the alloy 625 is not susceptible to pitting corrosion.

Keywords: Ni alloy, Alloy 625, UNS N06625, Cold-formed, Stress Corrosion Cracking (SCC), Electrochemistry and High Chlorides.

INTRODUCTION

Alloy 625 (UNS N06625) is an austenitic solid solution strengthened nickel-chromium-molybdenum alloy containing niobium. The high alloy content of alloy 625 enables it to withstand a wide variety of severe corrosive environments.¹⁻³ In mild environments, such as ambient atmosphere, fresh and seawater, neutral salts and alkaline media, there is almost no attack. In more severe corrosive environments, chromium provides resistance to oxidizing chemicals, whereas the high nickel and molybdenum contents make the alloy resistant to nonoxidizing environments and also makes this alloy very resistant to pitting and crevice corrosion. The added niobium (3 to 4%) acts to stabilize the alloy against sensitization during welding, thereby preventing subsequent intergranular attack.

Nickel and nickel-base alloys such as alloy 625 are in general not subject to chloride stress-corrosion cracking (SCC) as compared to stainless steels. High nickel content in alloy 625 is beneficial in resisting the SCC in high chloride aqueous environments.⁴ However, the SCC resistance in high chloride environments under cold formed conditions is not well known.

Stemmed from an application involving very high chlorides (50,000-75,000 ppm) and very low pH conditions where a cold formed (deformed) alloy 625 component is being used, a laboratory study was initiated to understand the SCC resistance. The operating temperature of this component under heavy brine is in the range of 200-300°F.

In this study SCC and electrochemical corrosion study were performed at two chloride concentrations to understand the SCC resistance and corrosion behavior of alloy 625. A 2 mm thick alloy 625 sheet metal in solution annealed at 871°C was received from a mill. The chemical composition of alloy 625 (N06625) sheet is provided in Table 1. Mechanical properties and the grain size of the sheet material are provided in Table 2.

Table 1: Chemical Composition of N06625 Sheet.

Element	Sheet (wt. %)	ASTM B 443 (UNS N06625)
Carbon	0.04	0.10 max.
Manganese	0.39	0.50 max.
Phosphorous	0.007	0.015 max.
Sulfur	0.0001	0.015 max.
Silicon	0.19	0.5 max.
Iron	4.32	5.0 max.
Chromium	21.92	20.0-23.0
Niobium + Tantalum	3.40	3.15-4.15
Cobalt	0.11	1.0 max.
Molybdenum	8.19	8.0-10.0
Aluminum	0.22	0.40 max.
Titanium	0.21	0.40 max.
Nickel*	60.9	58.0 min.
Copper	0.08	---
*Nickel by difference		

Table 2: Mechanical properties and grain size of N06625 Sheet.

Yield Strength (ksi) 0.2% offset	Tensile Strength (ksi)	Elongation (%) in 2-inch	Hardness (HV)	ASTM Grain Size
70.1	134.1	47	217	9.5

CORROSION TESTING

Cold forming

Six strips (100 mm x 10 mm x 1.0 mm) were section from the sheets, deburred the edges and glass bead blasted the surface and then cleaned with reverse-osmosis (RO) water and acetone. The strips were bend in U-shape as per ASTM G30 - 97(2016) standard.⁵ Figure 1 shows one of U-bend specimens. Quarter-inch holes were drilled at the legs and insulated bolt and nuts were used to fasten the specimens. All bent specimens were dye-penetrant tested and visually examined under the stereoscope for cracking and no cracks were observed at the apex of the specimens.

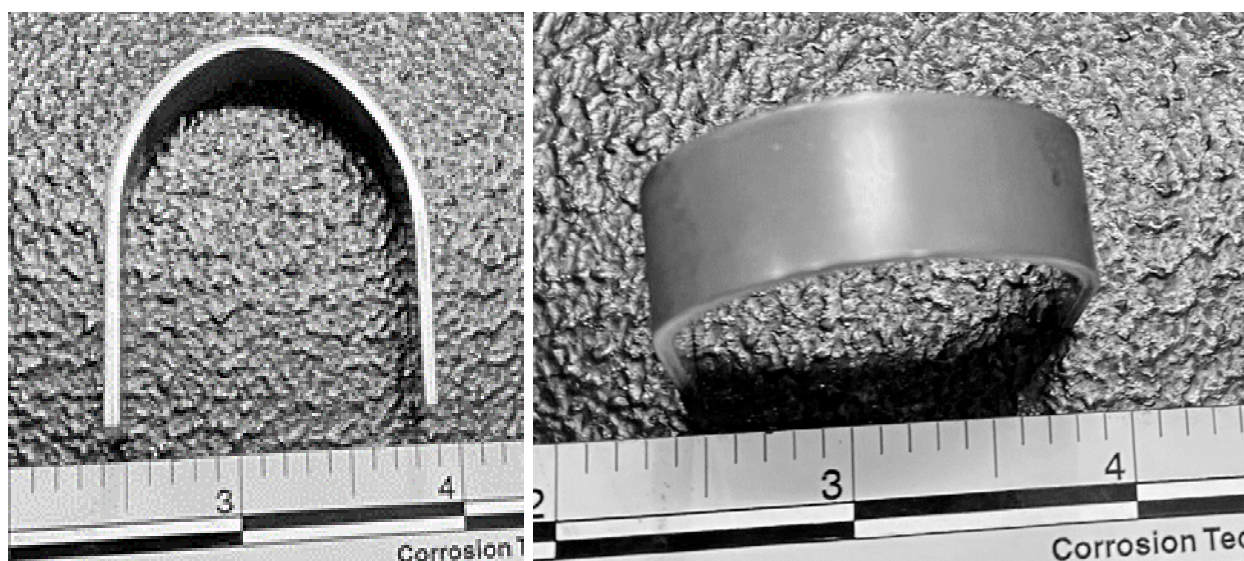


Figure 1. Photographs showing the U-bend specimen (left) and the apex stress location (right). Numbered scale divisions are inches.

Test Solutions

Two test solutions were prepared using sodium chloride (NaCl) salt and RO water, one with 50,000 ppm chlorides and another with 80,000 ppm chlorides. Both test solutions pH was adjusted to 1.0 using hydrochloric acid (HCl).

Stress Corrosion Cracking (SCC) Tests

Triplicate U-bend specimens were placed in a 2-liter reaction flask with condenser and filled with 80,000 ppm chloride solution and heated to boiling temperature. Same setup was used for 50,000 ppm chloride solution test. The tests were performed for 30 days in boiling solutions.

Electrochemical Corrosion Tests

Electrochemical test electrodes were prepared from the sheet material. Approximately 1 cm² area was exposed to the test solution and rest of the electrode was masked with high temperature, acid resistant, epoxy. A schematic of the test setup is shown in Figure 2.

Free corrosion potential (E_{corr})

Free corrosion potential (E_{corr}) was measured at 40°C until a stable potential was observed.

Linear Polarization Resistance (LPR) Scans

Linear polarization resistance (LPR) scans were then performed. The LPR scans were run from -20 mV to +20 mV with respect to E_{corr} at a scan rate of 0.167 mV/sec. Polarization resistance (R_p) of the corroding electrode was obtained from the slope of the potential versus current density plot. Based on a Stern-Geary coefficient of 0.12 V/decade, corrosion rates were then calculated using Gamry® software per the ASTM G 59 standard.⁶

Cyclic Potentiodynamic Polarization Scans

Cyclic potentiodynamic polarization scans were performed at 40°C in the above-mentioned test solutions by scanning from -0.1 V to +1 V (SCE) with respect to E_{corr} at 0.167 mV/sec scan rate (both forward and reverse scans) and 25mA/cm² apex current density. Note that these tests were conducted under naturally aerated conditions; no inert gas was purged for any of the tests.

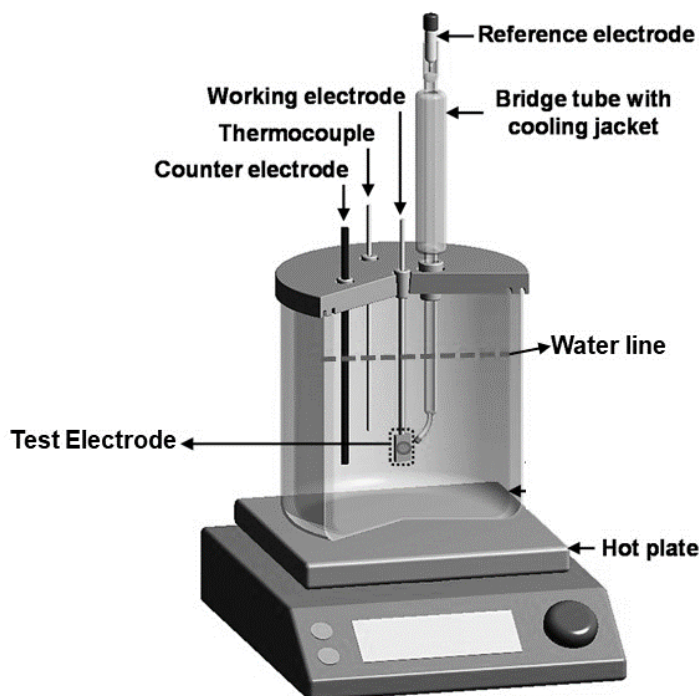


Figure 2: Schematic of electrochemical corrosion test setup.