Swagelok

Product Test Report

PTR-3074

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TITLE

Resistance of SAF 2507™ Super Duplex Stainless Steel to Chloride Stress Corrosion Cracking

PRODUCT TESTED

- Test samples were machined from Sandvik® SAF 2507 solution-annealed 1 in. dia. round bar and 13/16 in. cold-drawn hexagonal bar. Cold-reduction of the drawn bar was 27%.
- Mechanical properties of the bars were measured by a Swagelok-approved contract laboratory and are listed in Table I. Values are averages from two tensile tests.
- In Table I, the hardness of the cold-drawn hex bar was measured by Swagelok Company, while hardness of the solution-annealed bar was reported on Sandvik's certified material test report. Hardness was measured in both cases on a transverse cross-section of the bar.
- The solution-annealed round and cold-drawn hexagonal bars had identical heat code (TTW) and therefore, identical chemical composition (Table II).

Table I. Mechanical Properties of Tested Materials

Material Condition	**Yield Strength** ksi (MPa)	**Tensile Strength** ksi (MPa)	**Elongation** %	**Reduction of Area** %	**Hardness** HRC
Annealed	92 (634)	122 (841)	45	80	26
Cold-drawn	165 (1138)	170 (1172)	20	77	40

Table II. Chemical Composition of Tested Materials

C	Si	Mn	S	P	Cr	Mo	Ni	Co	N	Cu
0.013	0.29	0.43	0.0008	0.019	25.51	4.00	7.02	0.04	0.27	0.12

PURPOSE

This material was tested to observe the effect of material hardness on the resistance of SAF 2507 super duplex stainless steel to stress corrosion cracking in aqueous chloride solutions.

TEST CONDITIONS

Original test date: June 2012

- C-rings with 0.770 in. diameter, 0.750 in. width, and 0.075 in. thickness, were machined from the SAF 2507 bars.
- Bolts, nuts and washers machined from other SAF 2507 bars were used to compress the C-rings to generate tensile stresses corresponding to levels of 50%, 75%, and 100% of yield strength of the solution-annealed and cold-drawn materials, respectively (Figure 1).
- Corrosion tests were performed by immersing the pre-strained rings in an aqueous solution of 5-molar magnesium chloride ($MgCl_2$) at temperatures of 60, 80, 90,100, and 110°C for periods between 30 and 60 days.

- The chloride solution was contained in a glass vessel heated on a hot plate (Figure 2). Nitrogen was bubbled through the solution to minimize oxygen content and thus, pitting and crevice corrosion of the test assemblies. The temperature was monitored with a thermometer immersed in the solution.
- The rings were visually inspected each day (except for weekends) for presence of cracks. At the end of the test periods, the rings were inspected under an optical microscope (at 20x magnification) for presence of cracks.

Figure 1. Test assembly consisting of C-ring, ¼-28 bolt, nut and washers all machined from SAF 2507 super duplex stainless steel.

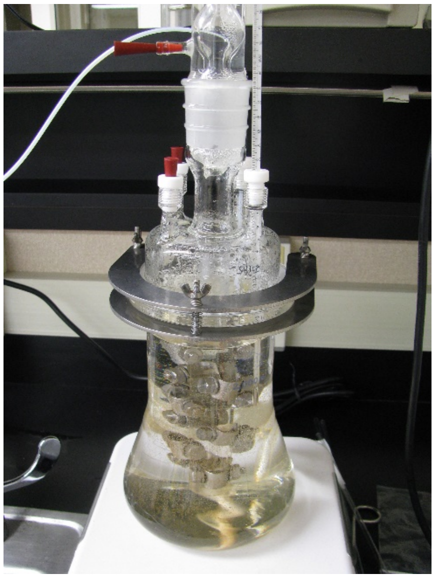

Figure 2. C-rings immersed in 5-molar solution of magnesium chloride. Rings are individually hung from glass hooks. Solution in glass vessel with condenser is continuously stirred and heated on hot plate.

TEST METHOD

- The corrosion tests were performed according to the requirements described in NACE standard TM0177-2005 (Ref. 1).
- Using the bolts and nuts, the C-rings were compressed to generate tensile stresses on their convex outer surface. According to the standard, the deflection necessary to obtain a desired level of tensile stress was calculated per Equation 1:

$$D = \pi d(d - t)\ S / 4tE \qquad \text{(Eq. 1)}$$

where
D = deflection of C-ring test specimen across bolt holes
d = C-ring test specimen outer diameter
t = C-ring test specimen thickness
S = desired outer fiber stress
E = modulus of elasticity

- Tensile stress levels of 50%, 75%, and 100% of yield strength of the solution-annealed and cold-drawn, respectively, materials were selected as the desired outer fiber stress S. For stress levels of 50% and 75%, Equation 1 was used to calculate the deflection. For the 100% stress level the deflection was calculated using an adjusted outer fiber stress S* in Equation 1, with S* calculated according to Equation 2:

$$S^* = S + E^*0.002 \qquad \text{(Eq. 2)}$$

- A value of 29.0 Msi (200 GPa) was used for the modulus of elasticity in Equations 1 and 2 (Ref. 2)

- While the TM0178-2005 standard describes details of C-ring sample preparation and performing the corrosion test, it does not specify the test medium. The standard requires a test duration of 30 days.

- The selection of the aqueous 5-molar $MgCl_2$ test solution was based on a publication from Drugli and Steinsmo (Ref. 3). These authors showed that immersion in this solution is representative of a corrosive condition caused by the deposition of seawater droplets on a substrate and subsequent water evaporation. The latter leads to an increase in the salt concentration of the remaining droplet, rendering the droplet more corrosive to the substrate. Seawater contains chlorides of sodium, magnesium, calcium, and other metals. Corrosion in concentrated solutions of magnesium chloride is more aggressive than corrosion in concentrated solutions of other metal chlorides typically found in seawater.

TEST RESULTS

Test parameters and results are shown in Table III.

Table III. Chloride Stress Cracking of SAF 2507 C-Rings

Temp. °C	Test Duration day	Material Condition	Stress Level (% Yield Str.)	Number of C-Rings Tested	Number of C-Rings Cracked	Time for Cracks to Become Visible day
60	30	annealed	100	3	0	n/a
60	30	cold-drawn	100	3	0	n/a
80	60	annealed	100	3	0	n/a
80	60	cold-drawn	100	3	0	n/a
90	60	annealed	100	3	1	35
90	60	annealed	75	3	0	n/a
90	60	cold-drawn	100	3	2	18, 60
90	60	cold-drawn	75	3	3	28, 28, 28
100	60	annealed	100	2	1	23
100	60	annealed	75	2	0	n/a
100	60	annealed	50	2	0	n/a
100	60	cold-drawn	100	2	2	7, 25
100	60	cold-drawn	75	2	2	25, 31
100	60	cold-drawn	50	2	1	25
110	30	annealed	100	3	3	4, 9, 16
110	30	cold-drawn	100	3	3	1, 1, 1

At temperatures of 60 and 80°C, C-rings from solution-annealed and cold-drawn, respectively, SAF 2507 did not show any signs of cracking after immersion in the test solution.

At 90°C and 100°C, the cold-worked material was more susceptible to cracking than the annealed material. Yet, cracking of the annealed material was observed, too.

All C-rings immersed at 110°C developed cracks within the 30-day test period. Cracks were found in 3 out of 3 rings from annealed, and 3 out of 3 rings from cold-drawn material. Time for cracks to become visible was shorter for C-rings machined from cold-drawn bar.

SUMMARY

At 60 to 80°C, cold-worked material with a hardness of 40 HRC had the same high resistance to chloride stress cracking as annealed SAF 2507. At 90°C, 100°C, and 110°C, both annealed and cold-worked materials were susceptible to cracking.

These tests were performed to consider a specific set of conditions and should not be considered valid outside those conditions. Swagelok Company makes no representation or warranties regarding these selected conditions or the results attained. Laboratory tests cannot duplicate the variety of actual operating conditions. Test results are not offered as statistically significant. See the product catalog for technical data.

SAFE PRODUCT SELECTION

When selecting a product, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

Referenced Documents

NACE Standard TM0177-2005: *Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H2S Environments*, NACE International, 1440 South Creek Drive, Houston, Texas 77084-4906, www.nace.org

Sandvik SAF 2507 Bar, online datasheet updated 2011-10-13, http://www.smt.sandvik.com/en/materials-center/material-datasheets/bar-and-hollow-bar/bar/sandvik-saf-2507/

J.M. Drugli and U. Steinsmo, *Assessment of Susceptibility to Chloride Stress Corrosion Cracking of Highly Alloyed Stainless Steels. Part II: A New Immersion Test Method,* NACE Corrosion 97 Paper No. 194 (1997).