Effect of Stress Level on the Stress Corrosion Cracking Initiation of Type 304L Stainless Steel Exposed to Simulated Sea Salt

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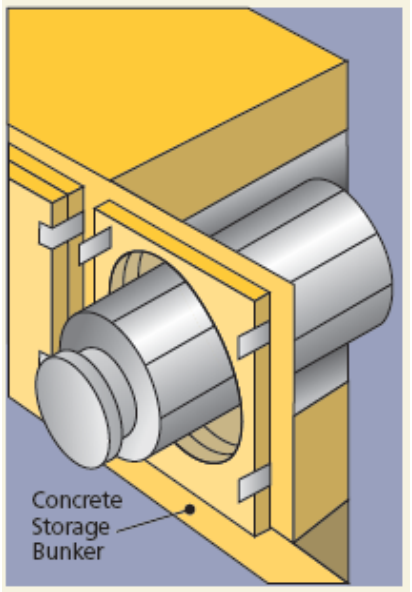
Dry Cask Storage System (DCSS)

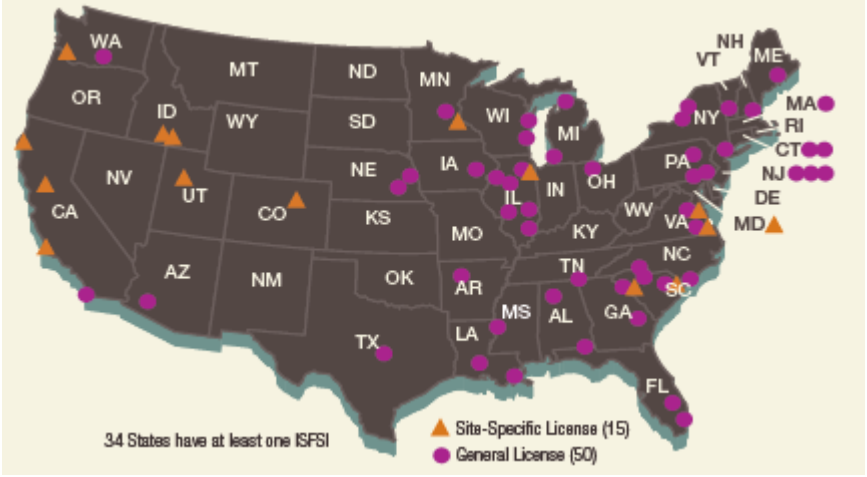


NRC NUREG–1350, 2012–2013

- After a period of cooling in the spent fuel pool, spent nuclear fuel (SNF) may be moved to dry storage
- DCSS are licensed for up to 40 years, with provisions for up to 40 year license renewals
- Most DCSS designs use a welded stainless steel canister inside an externally vented vault or overpack
  - Typical canisters are made of austenitic stainless steel (304/304L or 316/316L)

Independent Spent Fuel Storage Installation (ISFSI) Locations

- SNF may be placed in dry storage at ISFSIs licensed by NRC
- Some ISFSIs are located in areas with high airborne concentration of chloride-rich salts
  - Coastal, salted roads, cooling towers
- NRC is investigating the susceptibility dry storage canisters to chloride-induced SCC



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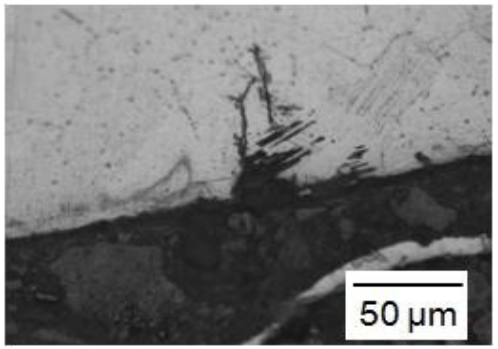
Results of U-Bend Testing

- Previous tests were performed using Type 304 U-bend specimens deposited with simulated sea salt.
- Specimens were exposed at temperatures between 27 and 80 ^{o}C, at various humidity levels and surface salt concentrations.
- SCC initiation was observed when the relative humidity (RH) was sufficiently high for deliquescence of the salt, above about 20 to 30%.



Specimens with 10 g/m^2 Salt, Exposed to Cyclic Humidity (15 to 30 g/m^3) at 45 °C for 4 Months

Motivation for Further Testing

- U-bend specimens represent only a single mechanical condition, with approximately 15 percent strain at the apex.
- Japanese studies have indicated chloride-induced SCC initiation on austenitic stainless steel at less than the yield stress with sustained load tensile specimens.[1]
- Canister weld stress and strain states have not been well-characterized, but experience from stainless steel piping welds indicates that residual strains in excess of 10 percent and through wall tensile stresses in excess of the yield stress are possible.[2]
- Further understanding of the effects of stress and strain on SCC initiation will be useful for assessing canister integrity.

[1]M. Mayuzumi, et al., Nuclear Engineering and Design, 238 (2008), 1,227–1,232.

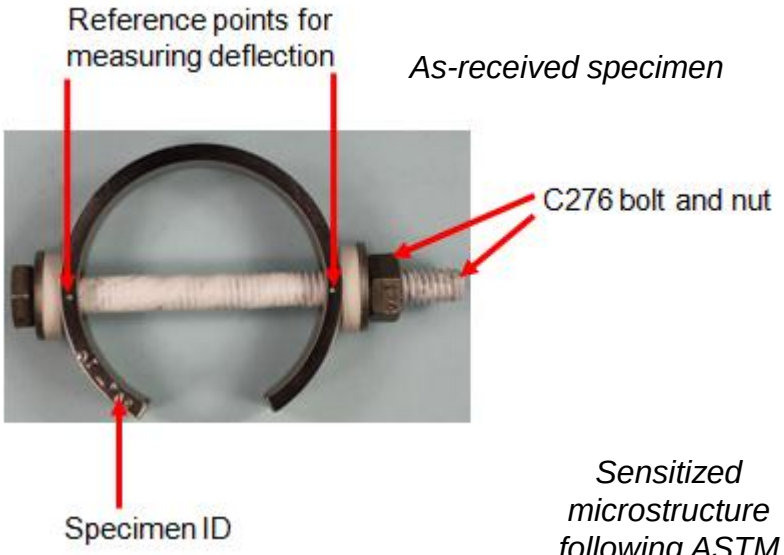
[2]P. Andresen, et al., CORROSION/2000, Paper 00203, NACE International (2000).

Testing Approach

- C-ring specimens fabricated from Type 304L stainless steel and strained to different levels. Some specimens are furnace sensitized.
- Specimens deposited with differing quantities of simulated sea salt.
- Specimens exposed for several months at various temperature and humidity levels.
- Specimens microscopically examined for evidence of SCC initiation.
- Parameters evaluated: strain level, salt quantity, temperature, humidity, material condition

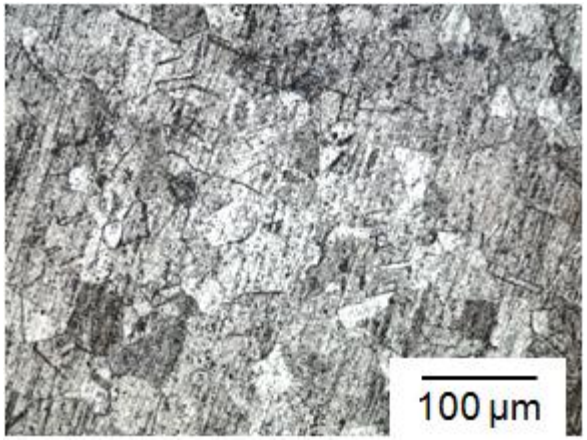
C-Ring Specimen Detail

- 304L stainless steel C-ring specimens (ASTM G-38)
  - As-received
  - Furnace sensitized
- Specimens strained by tightening nut on threaded bolt, calibrated by affixed strain gauge
  - 0.4 % strain (approximately material yield stress)
  - 1.5 % strain



As-received specimen

Sensitized microstructure following ASTM G108–94 test



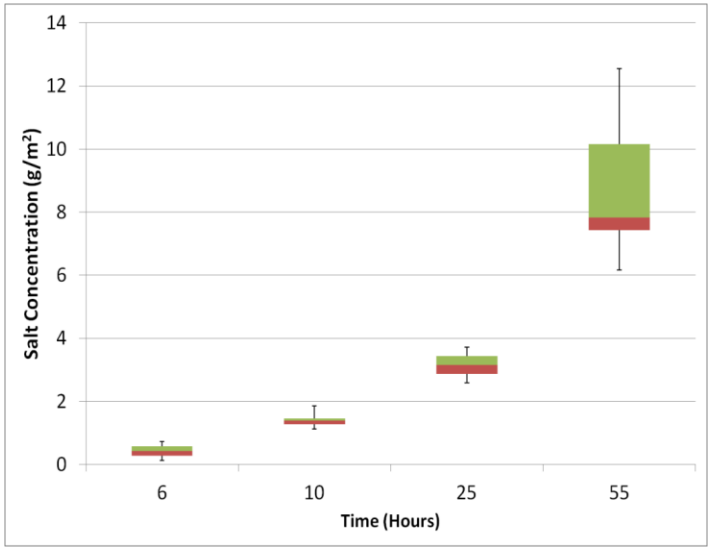
Chemical Composition of Type 304L Stainless Steels Used To Fabricate C-Rings (Wt%)

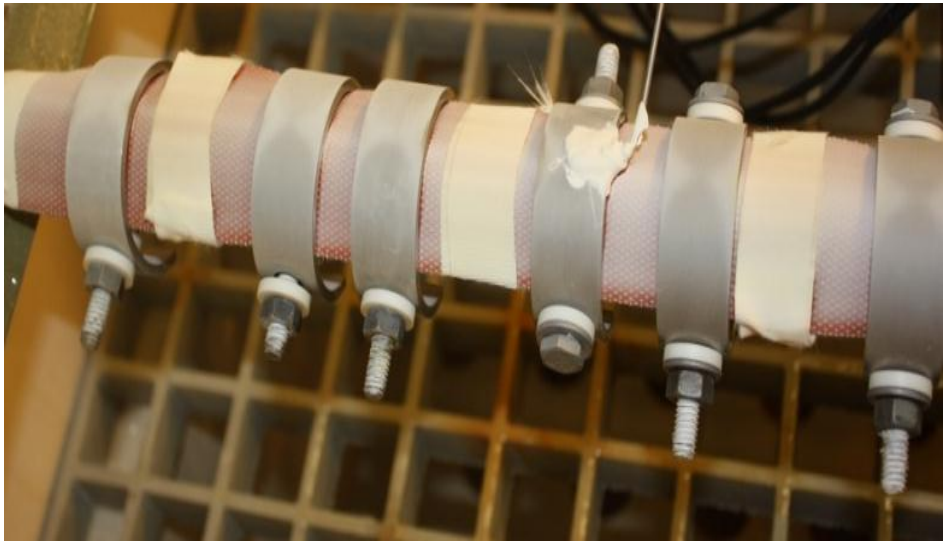
C	S	Mn	P	Si	Cr	Mo	Ni	Cu	Co	N	Fe
0.013	0.004	1.06	0.034	0.39	18.65	0.01	8.18	0.04	0.19	0.085	Balance

C = carbon S = sulfur Mn = manganese P = phosphorus Si = silicon Cr = chromium
Mo = molybdenum Ni = nickel Cu = copper Co = cobalt N = nitrogen Fe = iron

Salt Deposition Process

- Specimens were deposited with simulated sea salt (ASTM D1141–98) in quantities of 1.0 g/m^2 or 10.0 g/m^2.
- Salt was deposited by exposing specimens held at 90 °C to a salt fog and the quantity was determined by measuring weight gain.
- Specimens were examined to ensure no degradation occurred during salt deposition.





SCC Testing Protocol

- C-ring specimens exposed to controlled temperature and humidity conditions in environmental chambers.
- No introduction of liquid water so SCC would occur by salt deliquescence.
- Test conditions:
  - Temperature = 35, 45, or 52 °C
  - Absolute humidity = 29 g/m^3 (static)
  - Test duration = 2 to 3 months
  - 3 as-received and 3 sensitized specimens for each condition

C-Ring Stress Corrosion Cracking Test Matrix

Temp (°C)	Relative Humidity (%)	Absolute Humidity (g/m^3)	Salt Concentration (g/m^2)	Strain (%)	Maximum Test Duration (Month)
35	72	29	1	0.4	2
			10	0.4	3
45	44	29	1	0.4	3
			10	0.4	3
				1.5	2
52	32	29	1	0.4	2
			10	0.4	3
				1.5	2

Test Results

- SCC initiation was observed for specimens with as little as 0.4 percent strain, but on more specimens at 1.5 percent strain.
- Greater extent of cracking was observed at 52 °C compared to 35 or 45 °C
- Distinct trends were not clear for salt quantity and material condition.

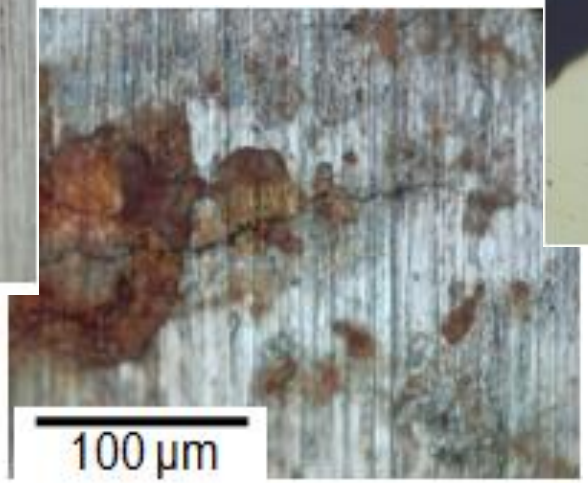
C-Ring Stress Corrosion Cracking Test Results

Temp (°C)	Relative Humidity (%)	Absolute Humidity (g/m^3)	Salt Concentration (g/m^2)	Strain (%)	Maximum Test Duration (Month)	Number of Cracked Specimens
35	72	29	1	0.4	2	0 As-Received 0 Sensitized
			10	0.4	3	0 As-Received 1 Sensitized
45	44	29	1	0.4	3	0 As-Received 0 Sensitized
			10	0.4	3	0 As-Received 0 Sensitized
				1.5	2	1 As-Received 1 Sensitized
52	32	29	1	0.4	2	3 As-Received 2 Sensitized
			10	0.4	3	0 As-Received 1 Sensitized
				1.5	2	3 As-Received 3 Sensitized

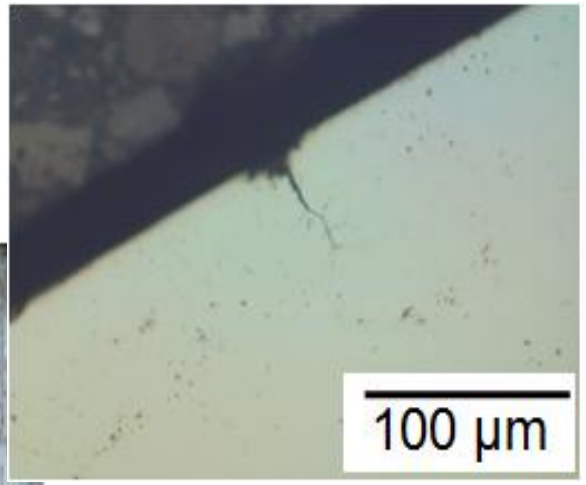
General Observations

- Cracks are located at pits
- Cracks have both intergranular and transgranular features
- No conclusions are drawn about depth of crack propagation or propagation rates.

1 g/m^2 sensitized exposed to 52 °C 32%RH with 0.4 percent strain



1 g/m^2 sensitized exposed to 52 °C 32%RH with 0.4 percent strain



10 g/m^2 sensitized exposed to 45 °C 44%RH with 1.5 percent strain

Conclusions

- SCC induced by chloride-salt deliquescence was observed on austenitic stainless steel specimens with lower strain than represented by U-bends.
- Cracking was observed at strain as low as 0.4 percent, but to a greater extent on specimens with higher strain.
- Cracking was observed at temperatures between 35 and 52 °C, but cracks were more extensive at 52 °C.
- Crack morphology appeared similar to those in U-bend specimens.