Evaluation of Coastal Salt Effects on the Stress Corrosion Cracking of Type 304 Stainless Steel

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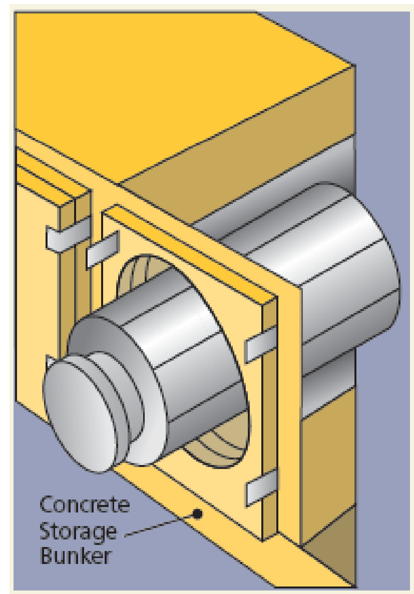
Dry Cask Storage System (DCSS)

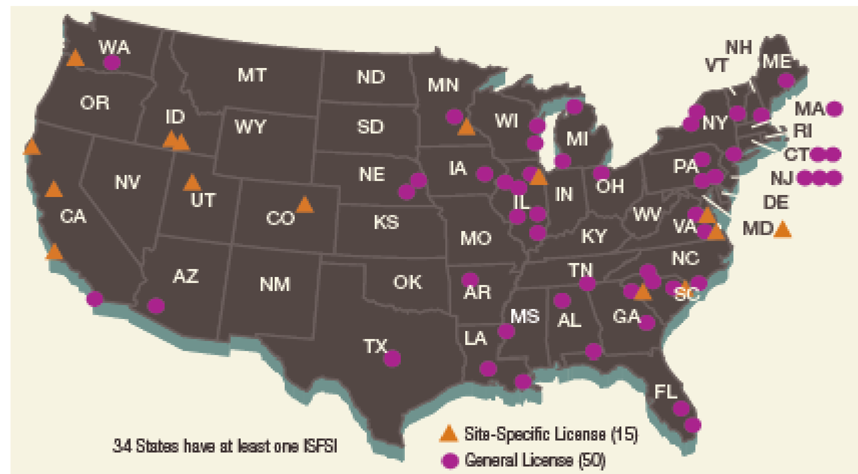


NRC NUREG–1350, 2012–2013

- 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

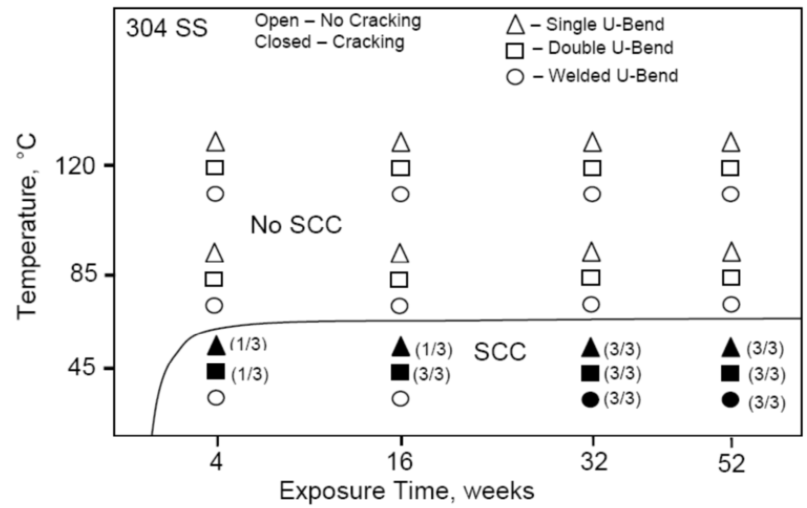
- SNF may be placed in dry storage at ISFSIs licensed by NRC under 10 CFR 72
- Some ISFSIs are located in areas with high airborne concentration of chloride-rich salts
  - Coastal, salted roads, cooling towers
- NRC is investigating the susceptibility of austenitic stainless steel dry storage canisters to chloride-induced SCC



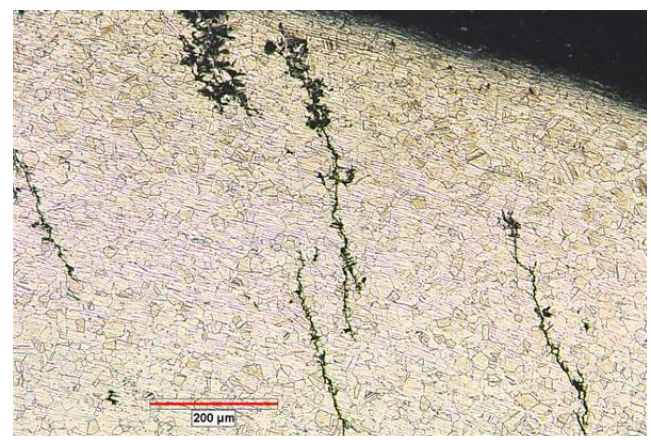
NRC NUREG–1350, 2012–2013

Results of Previous Study

- NRC previously conducted a study documented in NUREG/CR-7030
- U-bend specimens exposed to simulated sea salt fog conditions at 43, 85, and 120 °C
- Only specimens tested at 43 °C exhibited cracking
- Cracking susceptibility was related to the deliquescence of the deposited salt



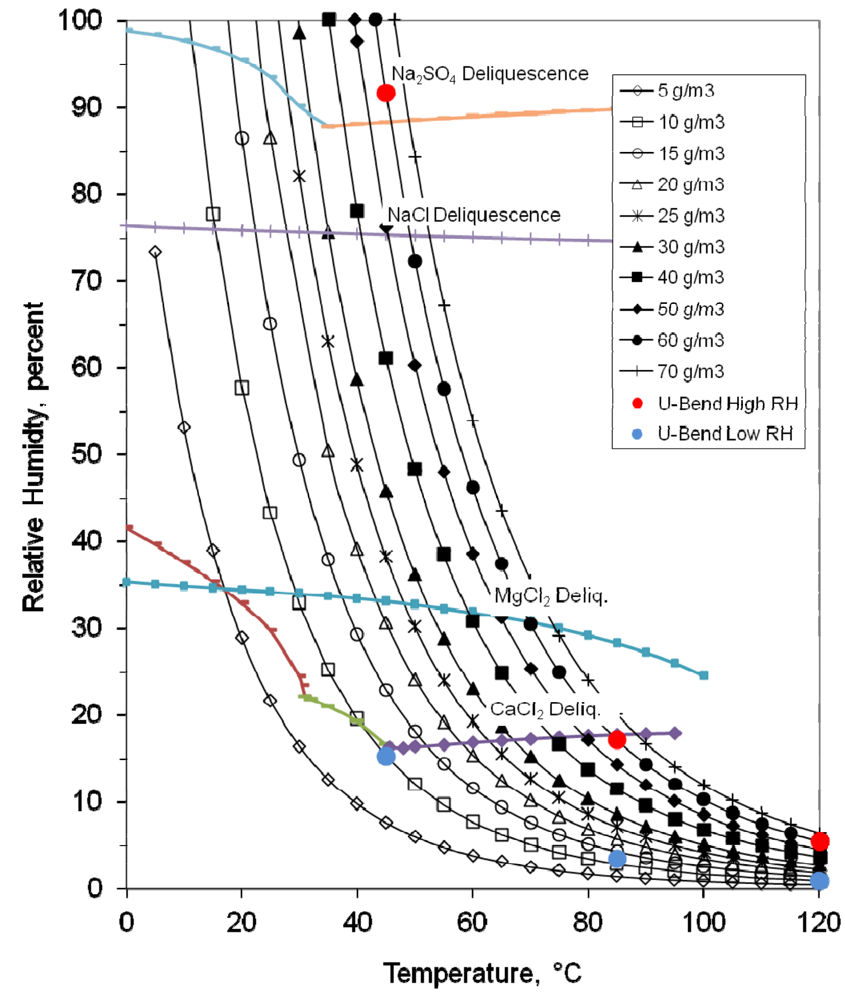
NUREG/CR–7030, 2010



Cracking in 32-week-exposed 304 Stainless Steel

Uncertainties with Previous Study

- Salt fog test protocol could introduce additional salt onto test specimens
- High absolute humidity in test chamber, approximately 60 g/m^3
- Limited control of salt quantity deposited on specimens, approximately 20 g/m^2
- Accelerated test conditions used are not likely to be representative of actual service conditions



Objectives of Present Study

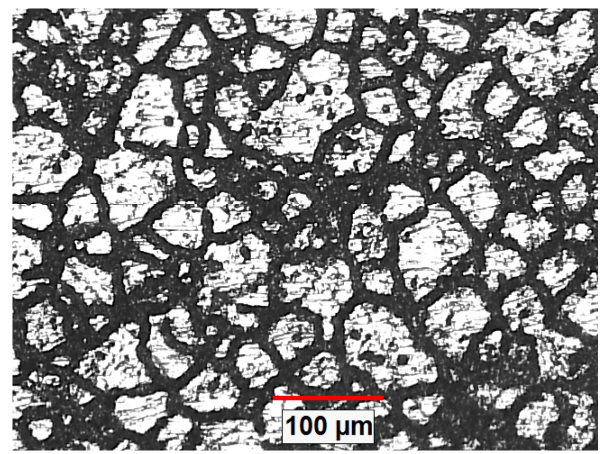
- Investigate the effects of humidity on susceptibility for crack initiation, particularly with respect to deliquescence relative humidity of sea salt and its constituents
- Investigate the effects of salt quantity on susceptibility for crack initiation
- Investigate the effects of temperature on susceptibility for crack initiation
- Investigate the effects of material condition on susceptibility for crack initiation

U-Bend Specimens

Tests were conducted using stainless steel U-bend specimens:

- Single 304 stainless steel (SS) U-bend specimens
  (ASTM G-30)
  - As-received
  - Sensitized
- Gas tungsten arc welded 304SS/308SS U-bends
  (ASTM G-58)
- Rolling direction was perpendicular to length

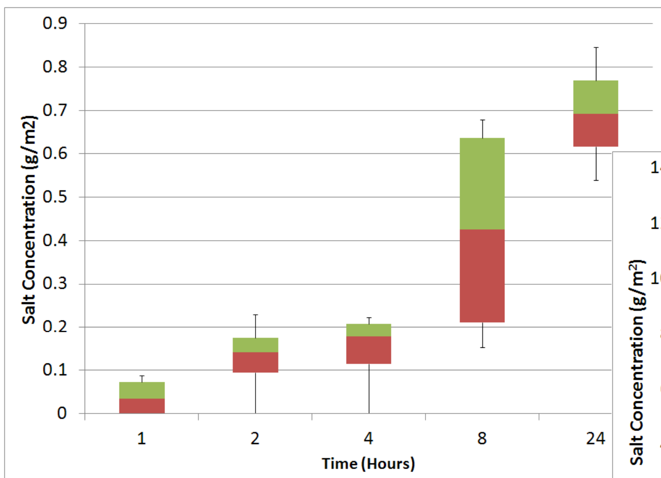
As-received specimen

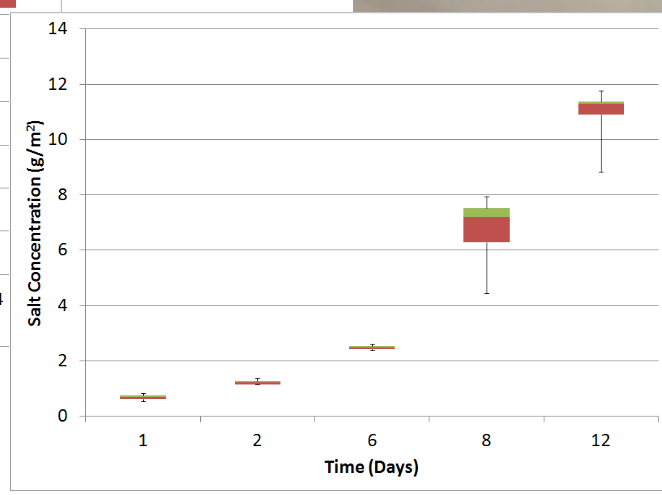


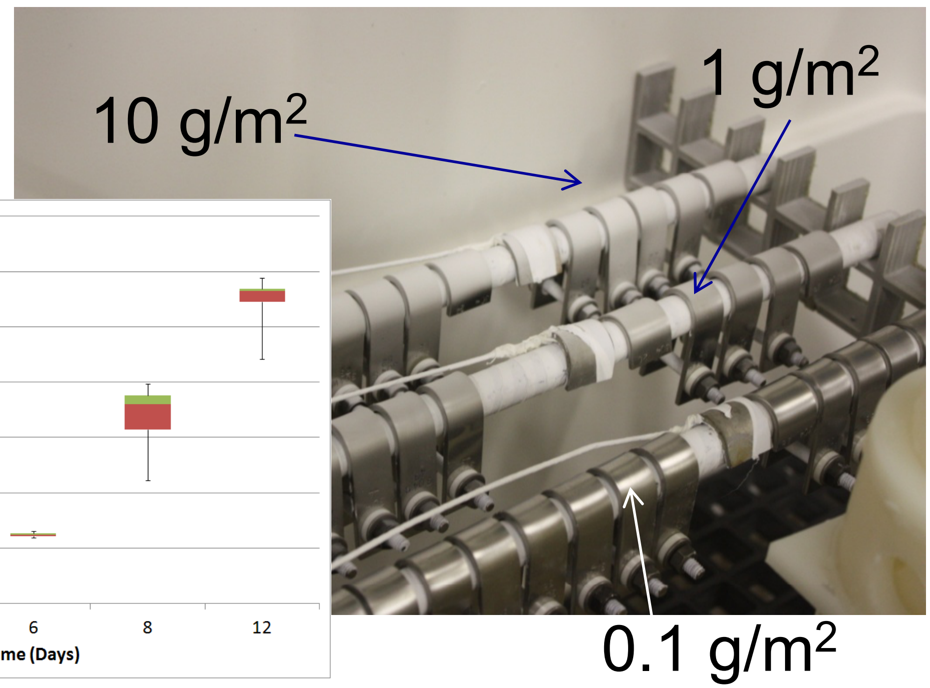
Sensitized microstrtucture following ASTM G108–94 test

Salt Deposition

- U-bend specimens were deposited with simulated sea salt (ASTM D1141–98) in quantities of 0.1 g/m^2, 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
  – Test samples were examined afterwards to ensure no degradation occurred under this process





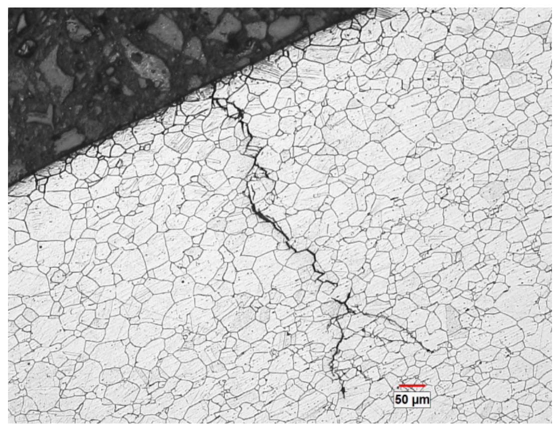


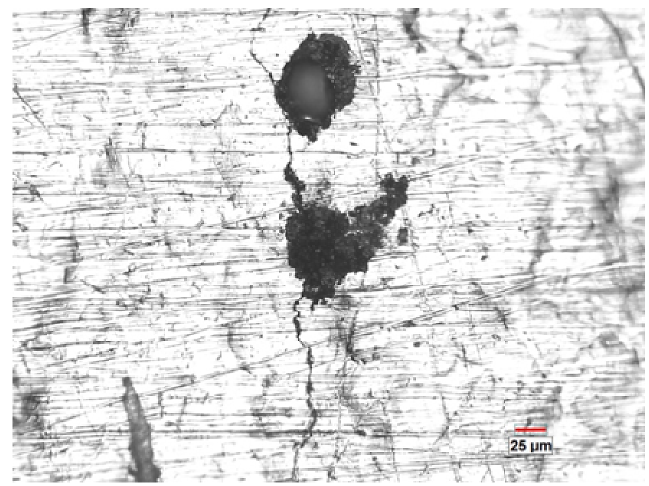
SCC Testing

- SCC tests were performed by placing U-bend specimens in environmental chambers and exposing the specimens to controlled temperature and humidity conditions
- Cyclic humidity tests
  - Absolute humidity cycle 4x per day between roughly 15 and 30 g/m^3
  - Temperatures between 35 and 52°C; Relative Humidity varies with specimen temperature
  - Salt quantities of 0.1, 1.0, or 10.0 g/m^2
  - As-received, sensitized, or welded condition
- Static humidity tests
  - Constant humidity conditions at predetermined levels
  - Temperatures at 60 or 80°C
  - Salt quantity of 10.0 g/m^2
  - As-received and sensitized condition

Cyclic Testing Observations

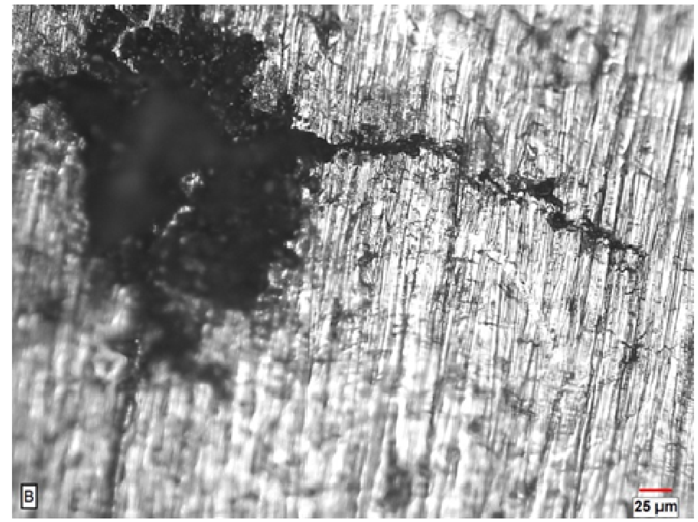
- SCC initiation was observed for specimens with as little as 0.1 g/m^2 of surface salt
- Sensitized specimens were more susceptible than the as-received and welded samples
- Corrosion appears as pitting on the specimen surfaces while cracks have intergranular and transgranular features



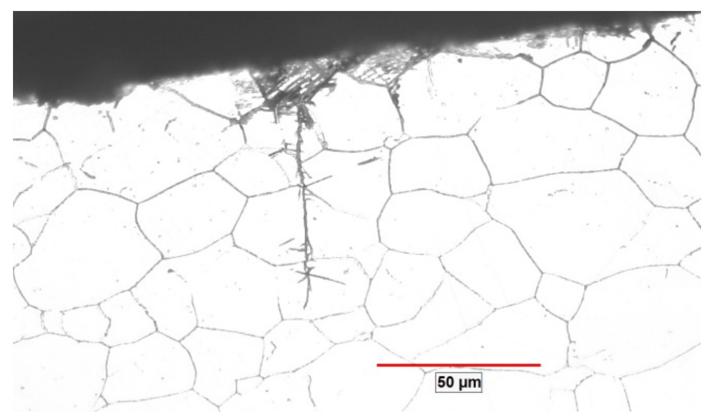


Static Testing Observations

- U-bend samples exposed to 45 °C at 44 percent relative humidity (not shown) exhibited cracks
- Cracking occurred in U-bend samples held at 60 °C when relative humidity increased above 25 percent and for U-bend samples held at 80 °C for 35 percent relative humidity and above.
- Sensitized specimens were more susceptible than the as-received and welded samples
- Corrosion morphology similar to cyclic testing observations



10 g/m² Sensitized exposed to 60 °C 35%RH



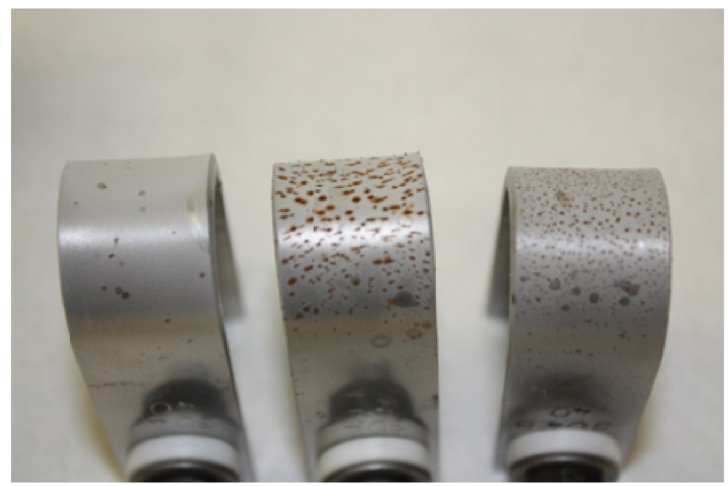
10 g/m² Sensitized U-Bend exposed to 80 °C 40% RH

Salt Concentration Observations

- 10 and 1 g/m^2 have whitish color with pitting clearly visible from the surface
- 0.1 g/m^2 appears pristine with very little evidence of pitting
- Cracks were evident on all three surface salt concentrations under cyclic test conditions

10 g/m^2 samples

0.1 g/m^2 samples

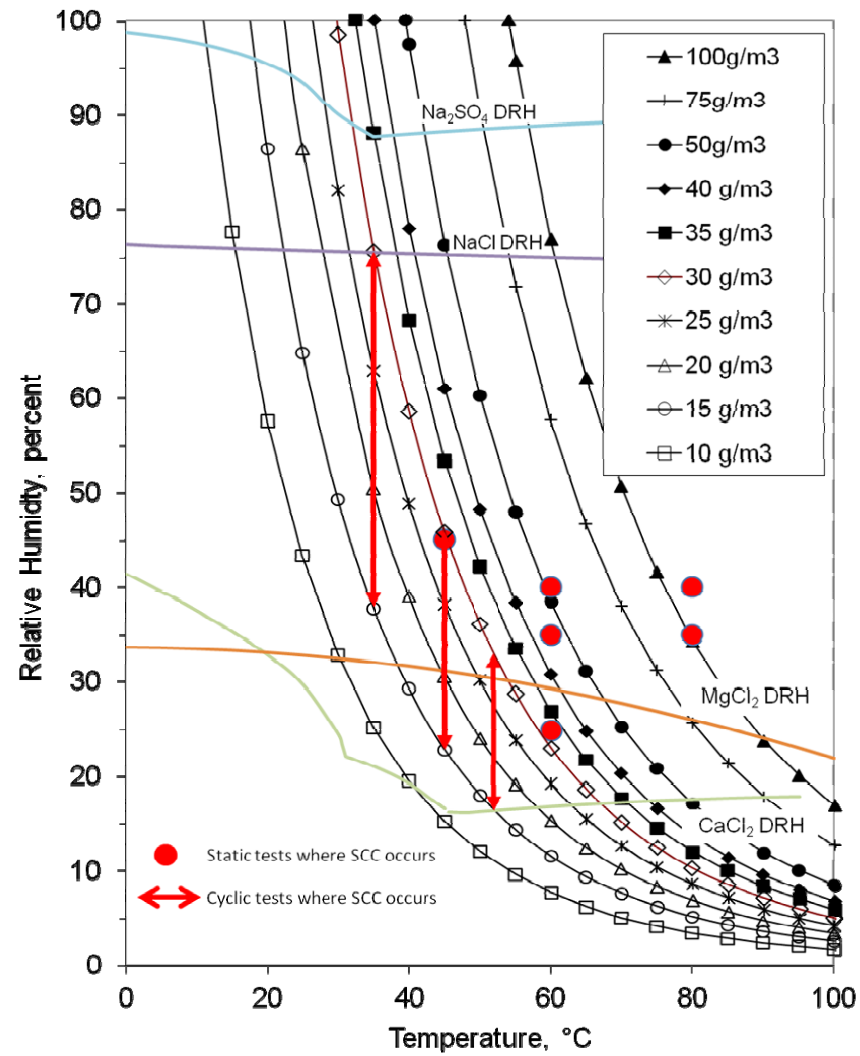


1 g/m^2 samples

Analysis of SCC Test Results under Both Cyclic and Static Conditions

- SCC susceptibility increases with increasing relative humidity suggesting a connection to a deliquescence relative humidity threshold

- Although NaCl is the most abundant constituent of sea salt, SCC occurred at humidity levels below NaCl deliquescence relative humidity indicating that $MgCl_2$ and $CaCl_2$ may play a critical role in SCC initiation



Conclusions

- This work investigated the SCC susceptibility of austenitic stainless steels exposed to a chloride-rich atmosphere
- Cracking was observed at as low as 0.1 g/m^2 but more extensive cracking was observed on higher surface salt concentrations
- Cracking was observed at temperatures between 35 and 80 °C as long as the relative humidity was maintained above the calcium chloride deliquescence relative humidity
- Ongoing tests are still being examined for both the cyclic and static atmospheric exposures

Acknowledgments

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