Atmospheric Salt Fog Testing to Evaluate Chloride Induced Stress Corrosion Cracking of Type 304, 304L, and 316L Stainless Steel

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Outline

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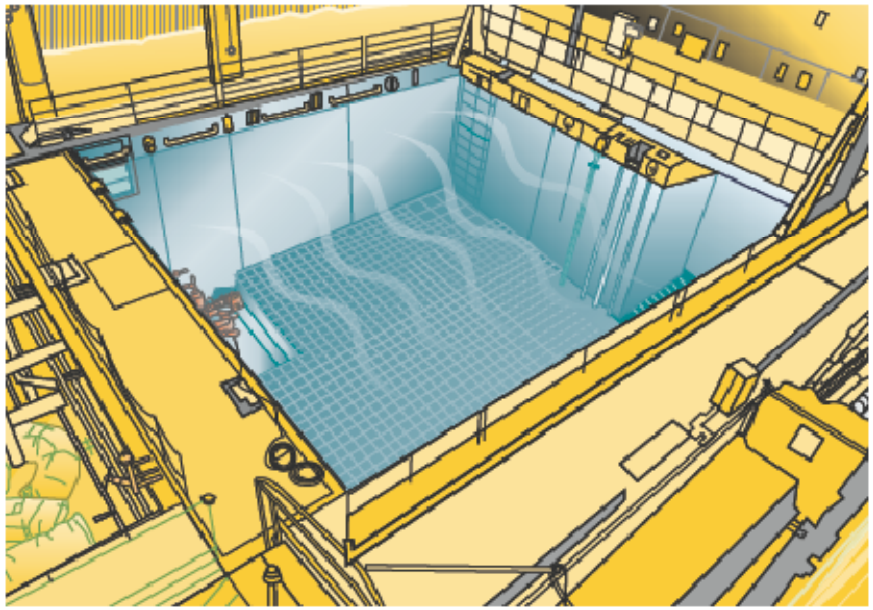
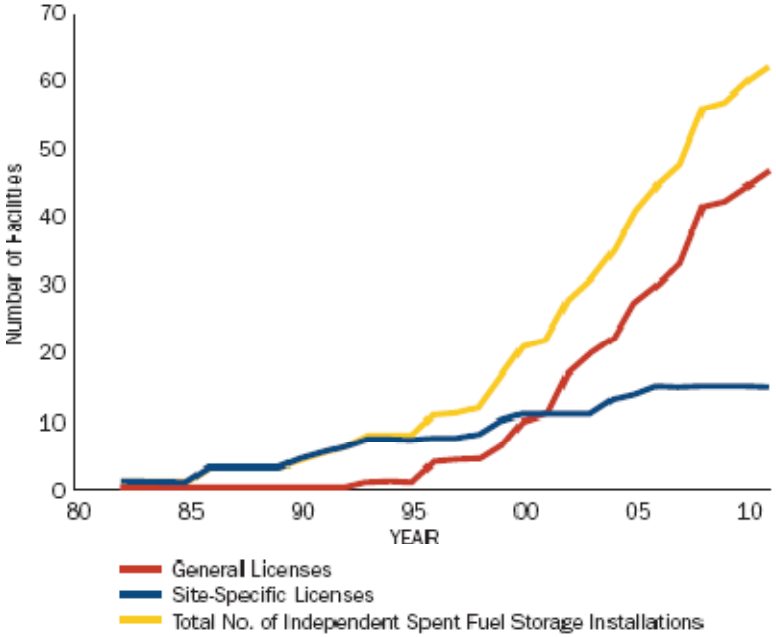
  - Dry Storage Facilities
  - Objectives
  - SCC of Austenitic Stainless Steel
- Technical Approach
  - Salt Deposition
  - Atmospheric Chamber Tests
- Experimental Results
- Conclusions

Spent Fuel Pools Reaching Capacity



NRC NUREG-1350

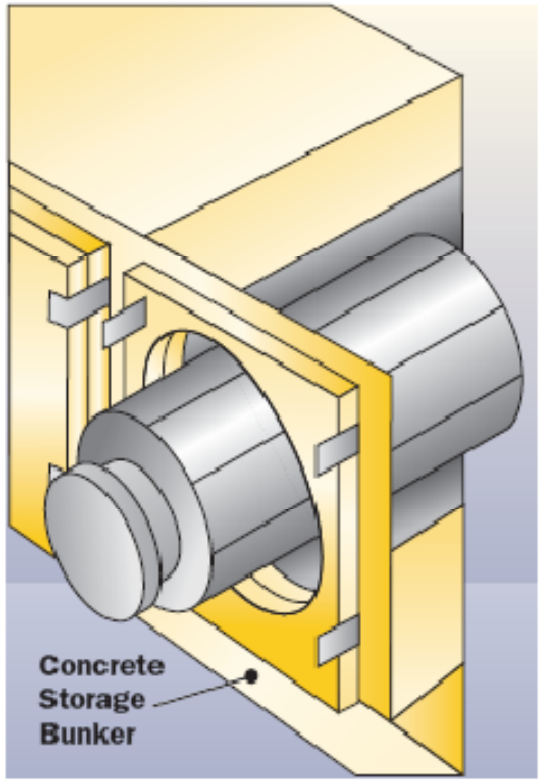


NRC NUREG-1350

- Commercial nuclear reactors refuel roughly every 18 to 24 months
  - Spent nuclear fuel is initially placed in spent fuel pools
  - The pools at many commercial nuclear power plants have or are reaching capacity

Dry Cask Storage System

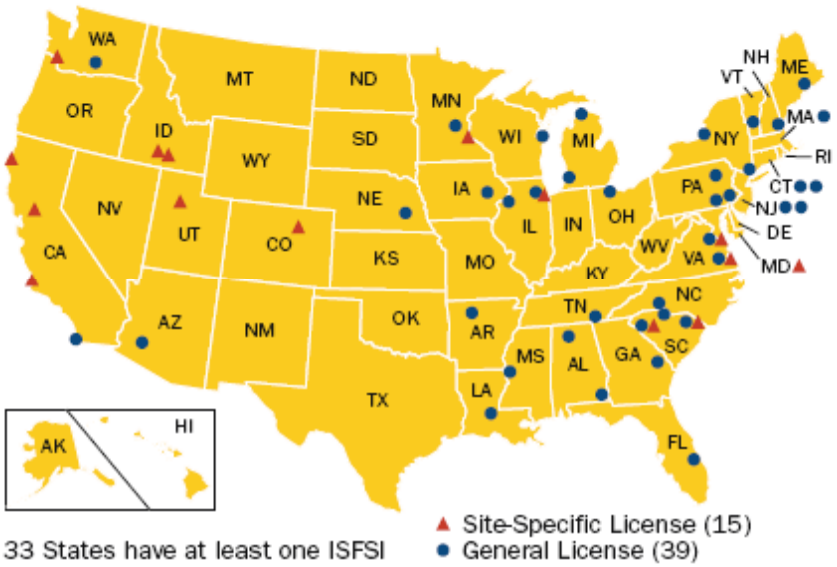
NRC NUREG-1350



- Nuclear power plants have turned to dry cask storage facilities
  - Most dry storage casks are made of austenitic stainless steel (304, 304L, and 316L)
  - Most systems use a stainless steel cask inside a concrete bunker or steel in a concrete cask with passive ventilation

Dry Cask Storage Locations

- Currently 33 Independent Spent Fuel Storage Installation (ISFSI) sites
- Some sites are located near coastal regions
- One recent concern is whether the dry storage casks are susceptible to chloride SCC



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Objective

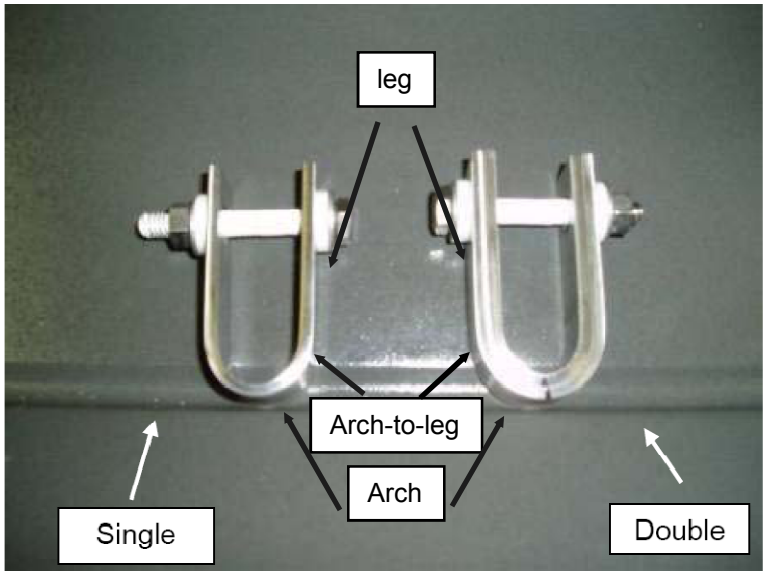
- To evaluate the susceptibility of austenitic type 304, 304L, and 316L stainless steel to chloride stress corrosion cracking (SCC) in environments typically found in dry cask storage facilities

Chloride SCC

- Chemical composition
  - Low susceptibility to sensitization of low carbon steel grades may reduce intergranular SCC susceptibility
  - Addition of molybdenum is suggested to enhance passivity and decrease SCC susceptibility
- Environmental chloride concentration
  - High chloride concentration leads to high probability of SCC
  - Coastal storage facilities may have a higher probability for SCC as a result of deposition of chloride containing aerosols
- Temperature
  - Low temperatures reduce probability for SCC initiation (below 50 °C [122 °F], the possibility of chloride SCC initiation is significantly reduced)

U-Bend Samples

- Stainless steel U-bend specimens tested:
  - Single and double U-bend specimens
    - 304, 304L, and 316L
  - Gas tungsten arc welded U-bends
    - 304/308, 304L/308L, and 316L/316L
  - Rolling direction was perpendicular to length

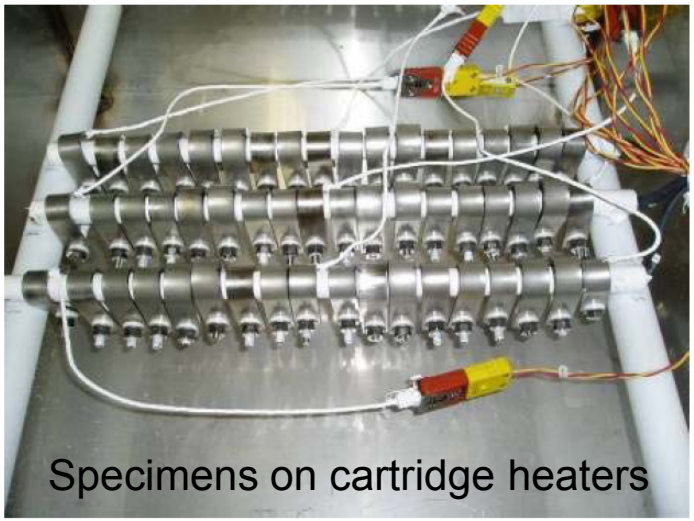


Chemical Composition

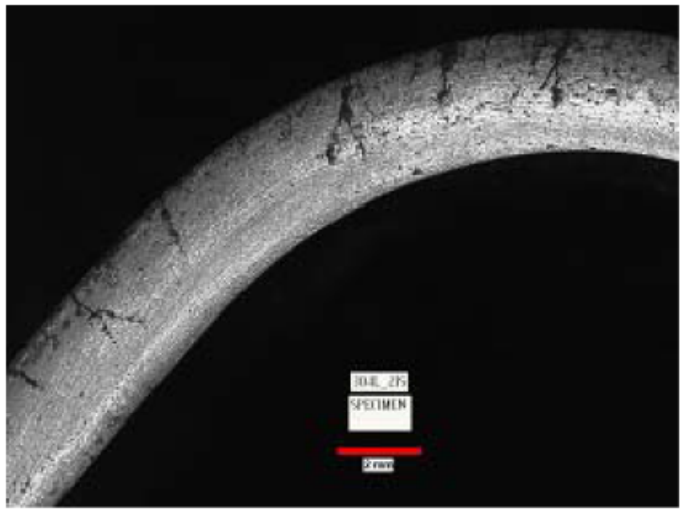
Material	Fe	Cr	Ni	Mo	Mn	C	S	P	N	Si	Cu
Type 304	Bal	18.19	8.07	N/A	1.21	0.039	0.002	0.026	0.042	0.55	N/A
Type 304L	Bal	18.14	8.07	0.18	1.29	0.025	0.001	0.025	0.032	0.34	0.27
Type 316L	Bal	16.43	10.13	2.06	1.35	0.019	0.0006	0.027	0.022	0.51	0.32
ER308	Bal	19.92	9.61	0.10	1.35	0.051	0.002	0.023	0.019	0.36	0.14
ER308L	Bal	20.12	9.79	0.05	1.75	0.009	0.010	0.014	0.043	0.47	0.05
ER316L	Bal	18.10	11.05	2.22	1.63	0.023	0.016	0.026	0.04	0.41	0.39

Initial Accelerated Tests

- Experiment
  - Type 304, 304L, 316L U-bends
  - Held samples at 25, 93, and 176 °C [77, 200, and 350 °F]
  - General Motors (GM) 9540P accelerated corrosion test with ASTM simulated sea salt
- Results
  - All high temperature specimens cracked within 1 month
  - Specimen temperature decreased when sprayed
  - Testing was overly conservative



Specimens on cartridge heaters



SCC of 304L SS exposed for 1 month at 93 °C

New Test Approach

- Test Requirements
  - A process to deposit salt realistically on the surface of the specimens
  - Wet/dry cycles to accelerate corrosion
  - Avoid direct seawater salt spray
- Materials
  - Evaluate 304, 304L, 316L and welded specimens

Salt Fog Test Method

- Two Phase Process
  - Salt Deposition

Cycle #	Chamber Cycle	Time, minutes	Chamber Temp, °C	Comments
1	Salt fog	5	30	Deposit Salt on specimens
2	Dry	15	30	Dry specimens after fog cycle

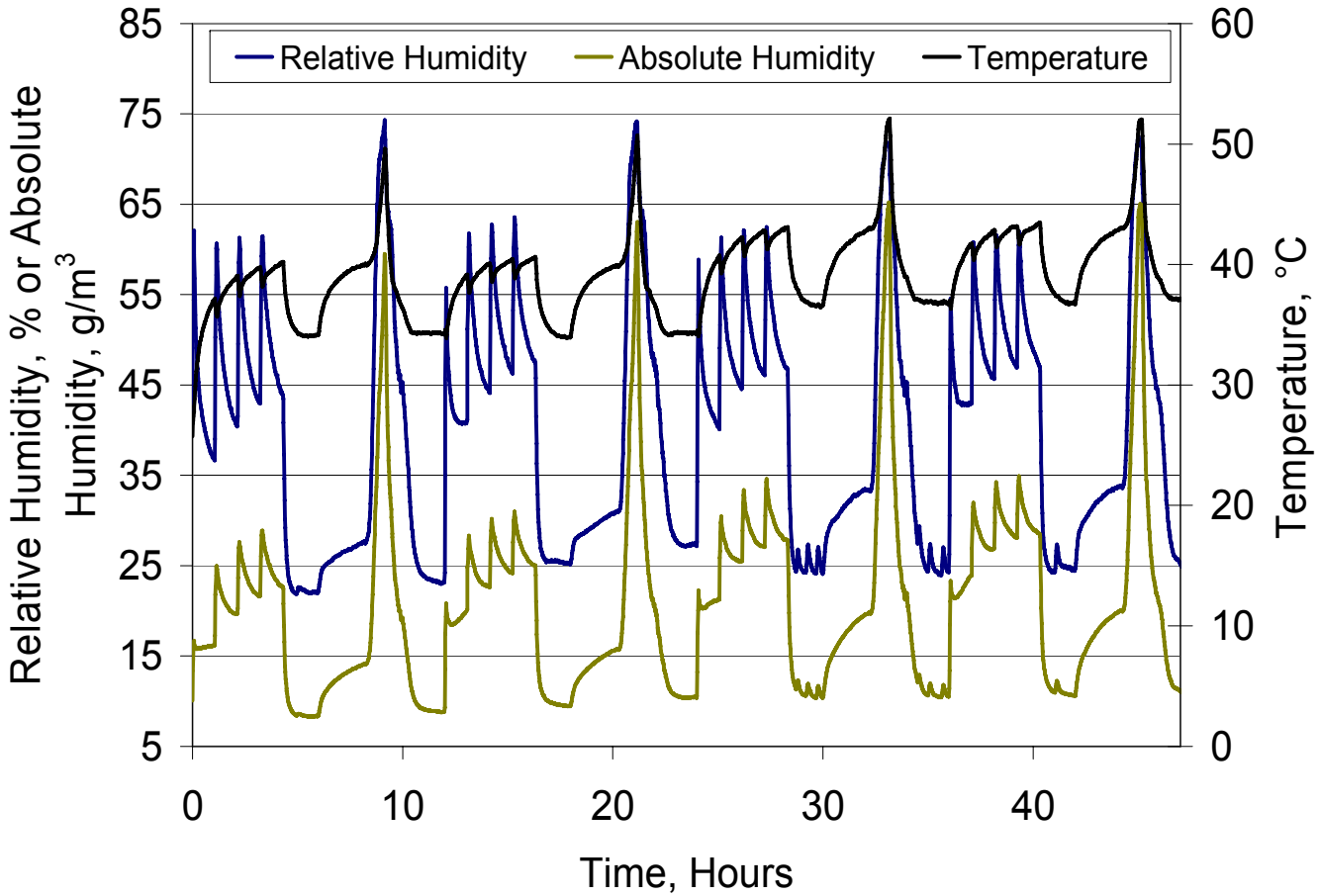
  - Wet/dry Cycling

Cycle #	Chamber Cycle	Time, minutes	Comments
1	Salt fog	5	Deposit salt on the specimens
2	Ambient	60	
3	Salt fog	5	Deposit salt on the specimens
4	Ambient	60	
5	Salt fog	5	Deposit salt on the specimens
6	Ambient	60	
7	Salt fog	5	Deposit salt on the specimens
8	Ambient	60	
9	Dry	100	Low relative humidity
10	Increase Humidity	125	Relative humidity in chamber increased
11	High Humidity	55	High relative humidity
12	Dry	180	Low relative humidity

  - 52 week exposure at 45, 85, and 120 °C [113, 185, 248 °F]
  - Modified GM 9540 using salt fog periods with a high humidity and an extended dry period

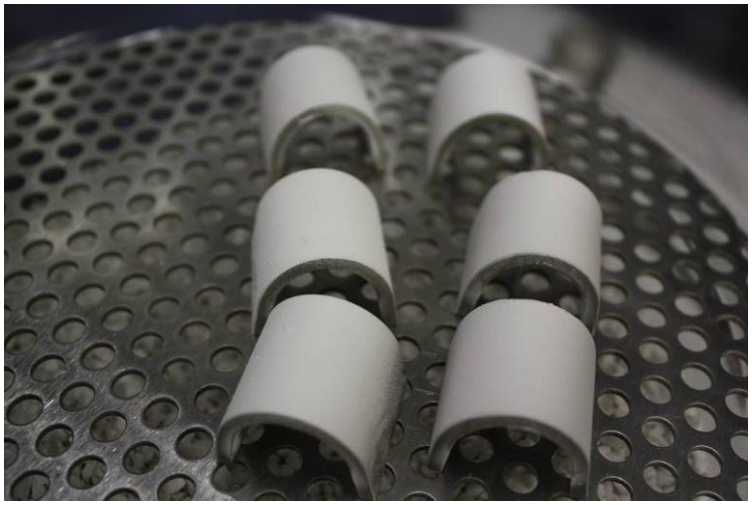
Test Conditions

- Thermal load in chamber required very high absolute humidity to reach needed relative humidity



Salt Deposition

- Initial deposition resulted in a salt deposit equivalent to roughly 6-18 months of natural accumulation
- Control tests showed no indication of corrosion after salt deposition
- Salt remained on the surface of the samples throughout overall exposure period

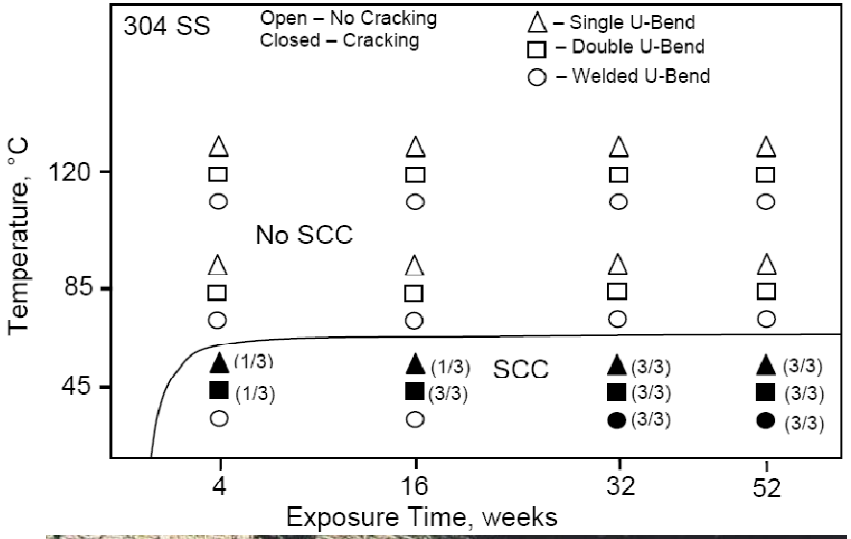


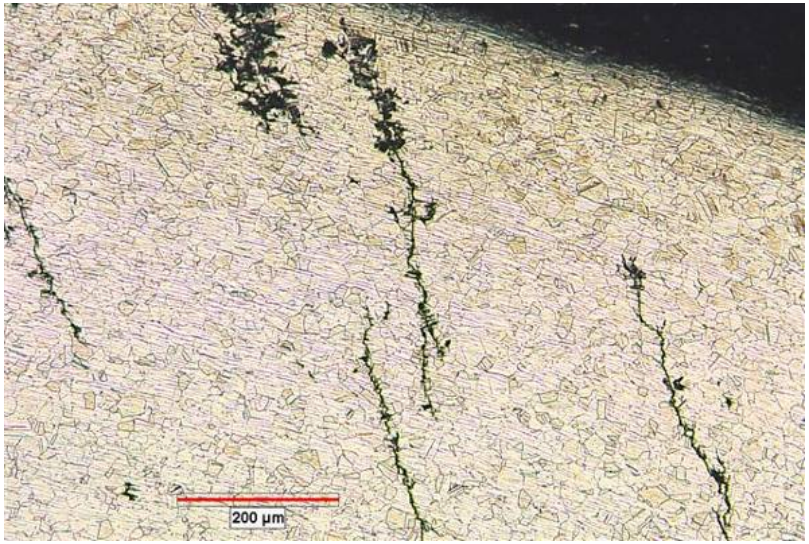
Temperature	4 Week Deposit, mg/m^2	16 Week Deposit, mg/m^2	32 Week Deposit, mg/m^2	52 week Deposit, mg/m^2
45 °C [113 °F]	51,847*	81,400*	144,770*	N/A
85 °C [185 °F]	27,667	34,700	66,960	88,815
120 °C [248 °F]	35,262	70,900	43,477	68,975

* Weight change is mainly due to corrosion product formation

Test Results (304 Stainless Steel)

- Cracking was only observed in low temperature samples
- Cracks observed to initiate after exposure for 4 weeks
- Cracking severity increased with exposure time
  - More samples cracked
  - Crack lengths increased

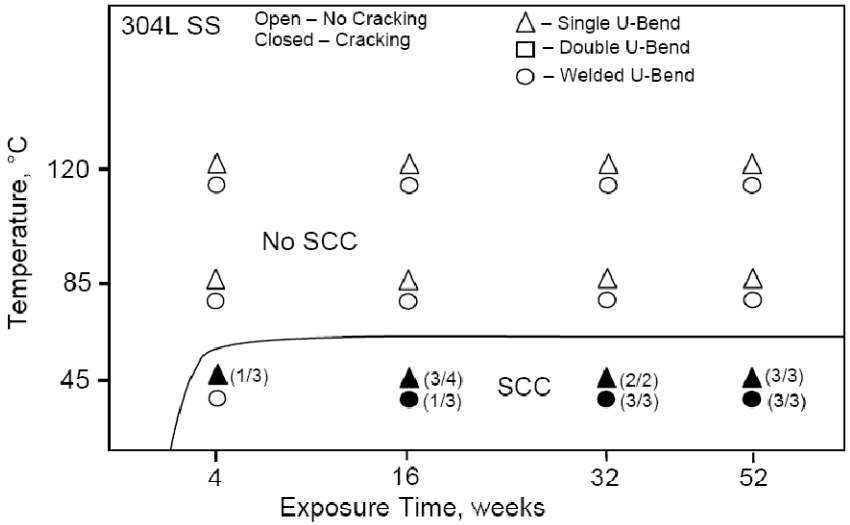


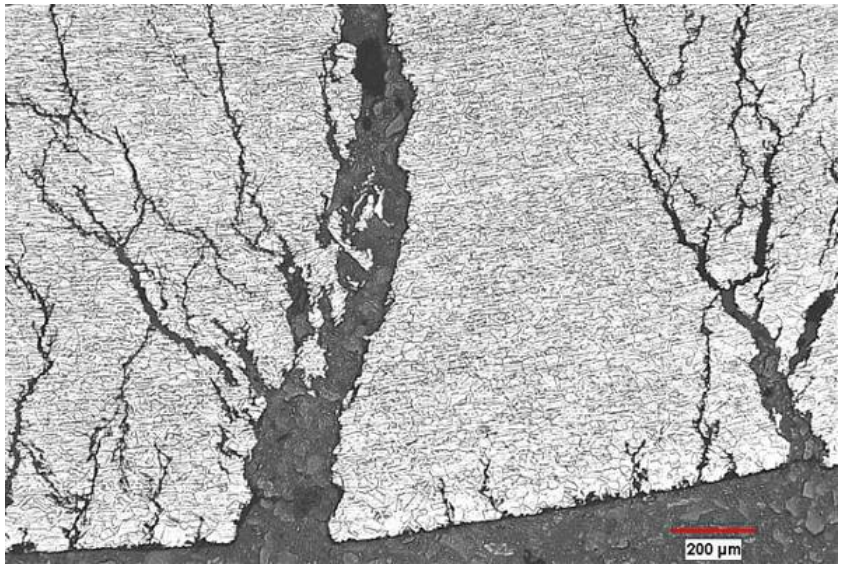


Cracking in 32 week exposed 304 Stainless Steel

Test Results (304L Stainless Steel)

- Cracking was only observed in low temperature samples
- Cracks observed to initiate after exposure for 4 weeks
- Cracking severity increased with exposure time
  - More samples cracked
  - Crack lengths increased

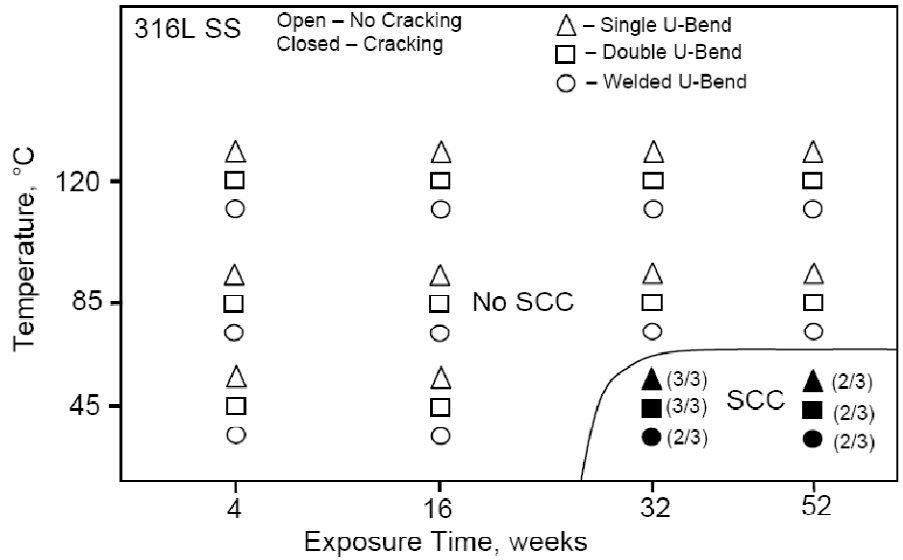


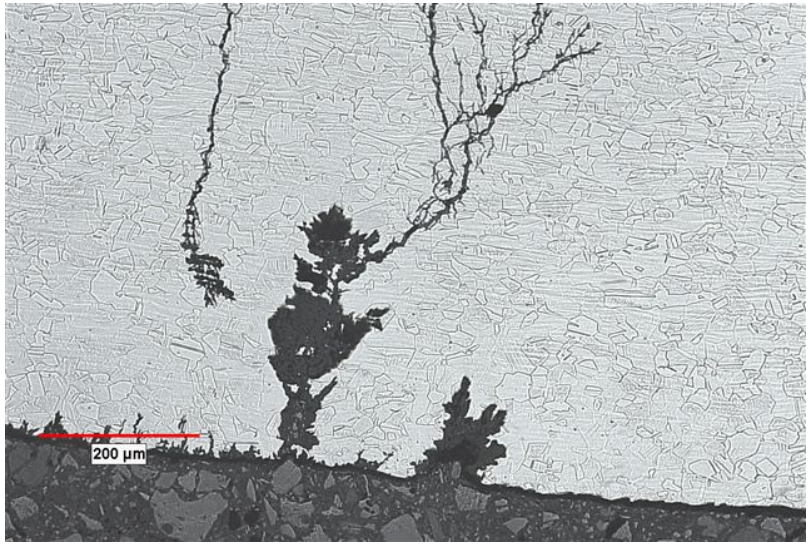


Cracking in 32 week exposed 304L Stainless Steel

Test Results (316L Stainless Steel)

- Cracking was only observed in low temperature samples
- Cracks observed to initiate after exposure for 32 weeks
- Cracking severity increased with exposure time
  - More samples cracked
  - Crack lengths increased

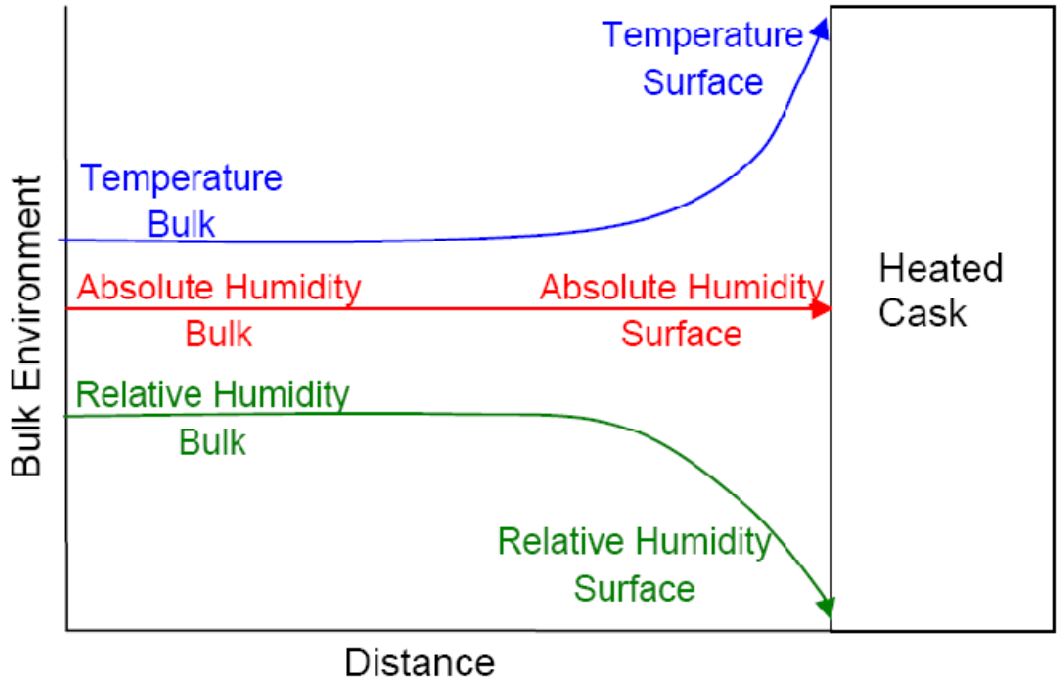




Cracking in 32 week exposed 316L Stainless Steel

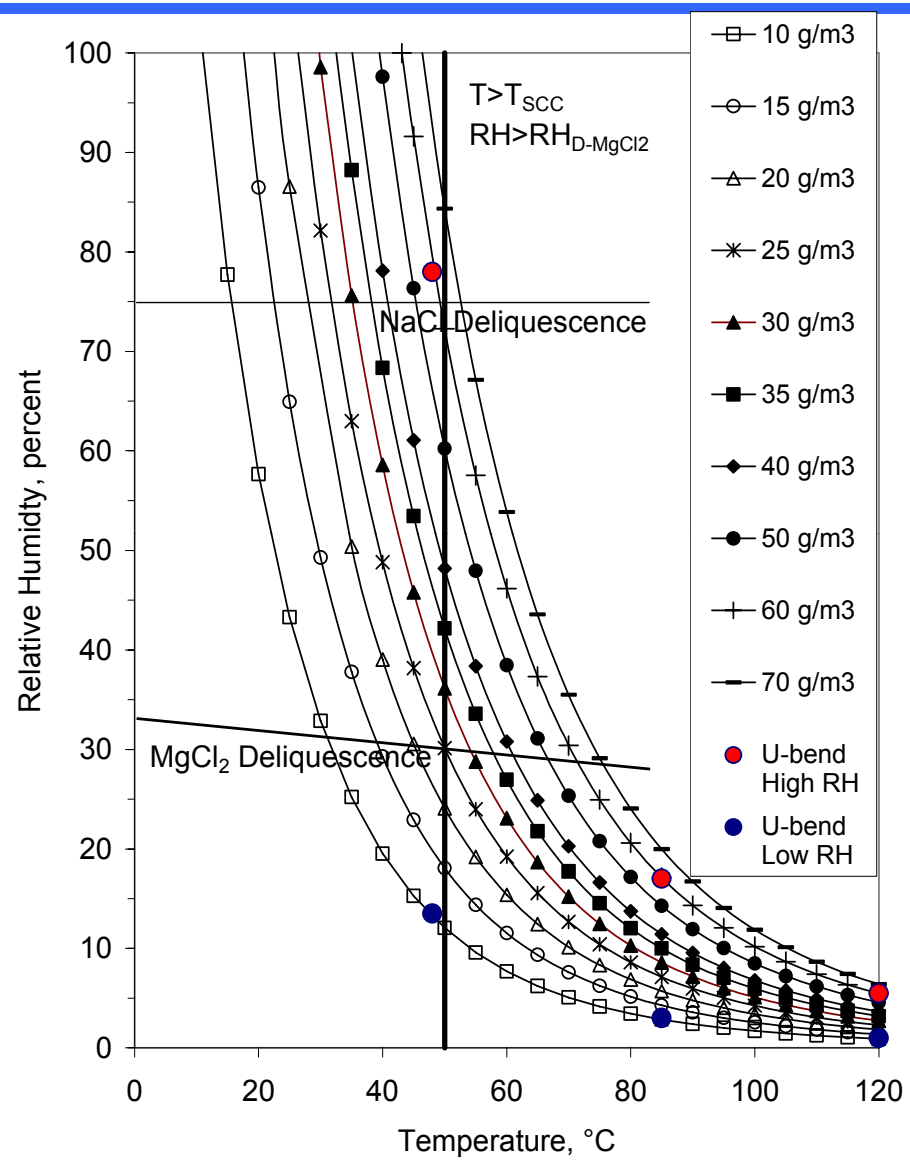
Stress Corrosion Cracking Analysis

- Air temperature increases near the sample surface
- Absolute humidity remains similar to bulk environment
- Relative humidity decreases near the sample surface



Stress Corrosion Cracking Analysis

- Typically, the maximum observed absolute humidity in natural environments is less than 30 g/m^2
- Test used conservative absolute humidity of 60 g/m^2
- High absolute humidity was sufficient to exceed the relative humidity necessary for the deliquescence of salts deposited on specimens maintained at 45 °C



Conclusion

- SCC observed on 304 and 304L stainless steel specimens held at 45 °C [113 °C] after exposure for a period of 4 weeks
  - Absolute humidity high for natural environment
- SCC observed on 316L after testing for 32 weeks
  - Marginal increase in SCC resistance compared to 304 and 304L stainless steel
- No SCC on specimens tested at 85 and 120 °C [185 and 248 °F]
  - No deliquescence at high temperature because of lower RH

Acknowledgements

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