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Corrosion Performance of Neutron-Absorbing Borated Stainless Steel

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Borated Stainless Steel

- Borated stainless steel is one of the materials used in spent fuel storage, transportation, and disposal to prevent nuclear criticality
- Chemical composition of borated stainless steel S30460–67 per ASTM A887–89*

Elements	C	P	Si	Ni	N	Mn	S	Cr	B	Fe
Weight percent	0.08 max	0.045 max	0.75 max	12.00 to 15.00	0.10 max	2.00 max	0.030 max	18.00 to 20.00	**2.25 max**	Bal

- Effects of boron content

Boron Content (%): 0.45, 0.72, 0.97, 1.20, 1.48, 1.75, 2.03, 2.23

→ Hardness, tensile strength, yield strength

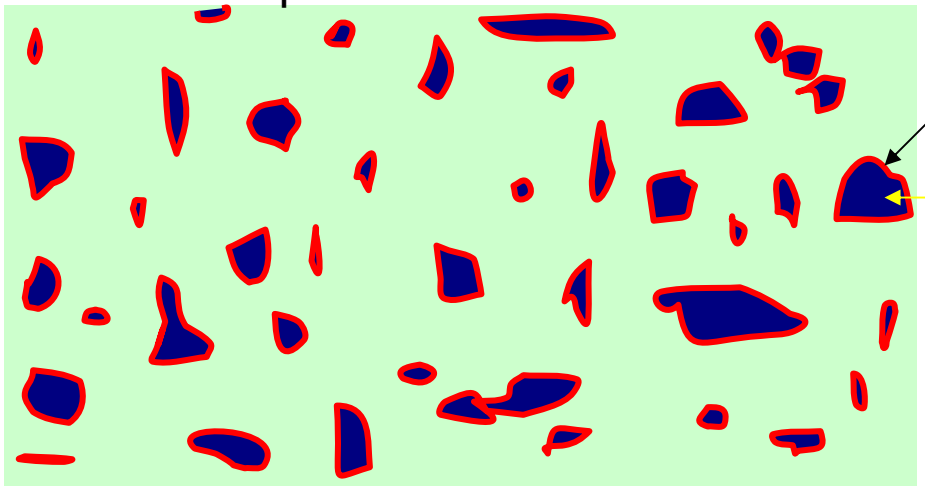
← Tensile ductility, impact toughness, corrosion resistance

* ASTM International. "ASTM A887-89 (2004): Standard Specification for Borated Stainless Steel Plate, Sheet, and Strip for Nuclear Application." Published on CD-ROM. West Conshohocken, Pennsylvania: ASTM International. 2008.

Microstructure of Borated Stainless Steel

- Boron is essentially insoluble in iron
- Primary austenite with boron-containing secondary phase intergranular particles, Fe_2B and Cr_2B, which leads to
  - Depletion of chromium in regions adjacent to the particles
  - Different corrosion behavior from austenite stainless steel

Distribution of particles in the austenitic matrix



Chromium depletion region

Boron-concentrated particles

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Common Forms of Stainless Steel Corrosion in Aqueous Environment

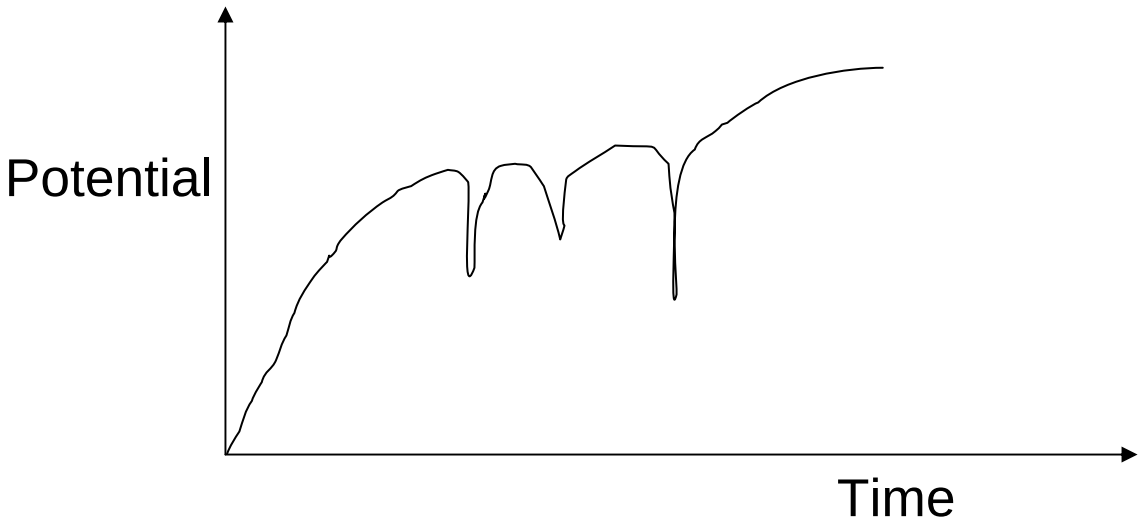
Corrosion Forms	Stainless Steel S304	Borated Stainless Steel S304
General corrosion	Yes	Yes
Pitting corrosion	Yes (Especially in Cl^- solution*)	Yes (Especially in Cl^- solution)
Crevice corrosion	Yes	Yes
Galvanic corrosion	Yes	Yes
Intergranular corrosion	Yes (Especially after sensitization)	Yes
Stress-corrosion cracking	Yes	Yes

* In oxygen-saturated water containing 100 ppm Cl^-, pitting occurs even at room temperature. (Grubb, J.F., T. DeBold, and J.D. Fritz. "Corrosion of Wrought Stainless Steels." *Corrosion: Materials*. Vol. 13B. Metals Park, Ohio: ASM International. pp 54–77. 2005.)

Corrosion Behavior in Simulated Groundwaters*

- Negative excursions of open circuit potential at 60 °C indicated localized corrosion initiations

Example of open circuit potential evolution with time

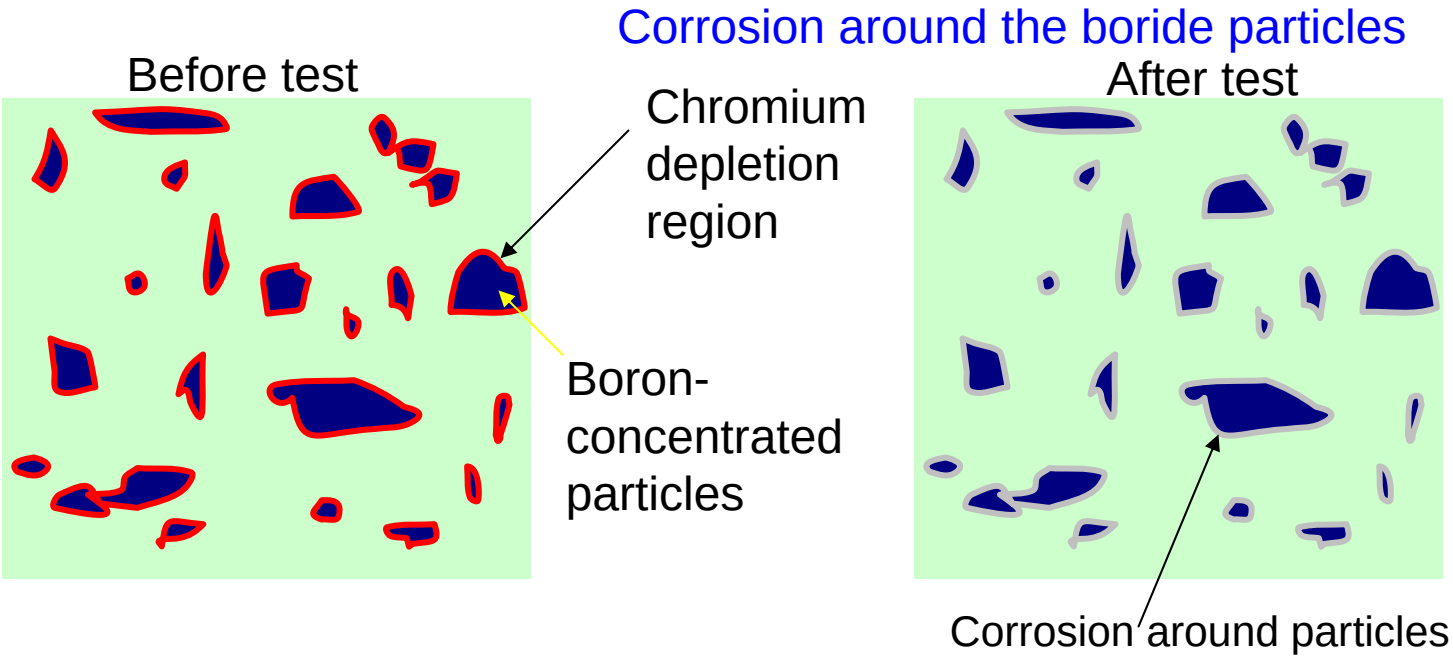


- Pitting corrosion is more evident than other forms of corrosion after open circuit and polarization tests

* Mizia, R.E., T.E. Lister, A.W. Erickson, and T.L. Trowbridge. "Corrosion Performance Comparison of Neutron Absorbing Alloys." Proceedings of the CORROSION '08 Conference. Paper No. 592. Houston, Texas: NACE International. 2008.

Localized Corrosion of Borated Stainless Steel

- Localized corrosion occurred around chromium-rich borides, which allowed them to detach from the surface*



- Boron remained with the particles and was not detected in solution as soluble species

* Lister, T.E., R.E. Mizia, A.W. Erickson, and B.S. Matteson. "General and Localized Corrosion of Borated Stainless Steels." Proceedings of the CORROSION '08 Conference. Paper No. 590. Houston, Texas: NACE International. 2008.

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Corrosion Behavior in Simulated Concentrated Groundwaters*

- Materials tested: 304 stainless steel (S30400), 316 stainless steel (S31600), Neutrosorb plus (S30467), Neutronit A978 (Type 316B7)
- Borated stainless steels were less resistant to corrosion than the witness austenitic materials (304 and 316 stainless steel)
- General corrosion, localized attack, and corrosion of chromium boride particles was observed

* Fix, D.V., J.C. Estill, L.L. Wong, and R.B. Rebak. "General and Localized Corrosion of Austenitic and Borated Stainless Steels in Simulated Concentrated Ground Waters." PVP-Vol. 483: Transportation, Storage, and Disposal of Radioactive Materials. San Diego, California. ASME. 2004.

Literature Reported General Corrosion Rates of Borated Stainless Steel at Different Environments

- Comparison of corrosion rates of neutron-absorbing materials*

Absorbing Material	Corrosion Rate	Notes
Ni-Gd alloy	Average value 0.056 µm/yr	30 °C, J-13 solutions
Ni-Gd alloy	Average value 0.307 µm/yr	60 °C, J-13 solutions
Borated stainless steel ASTM 304B4 Grade A alloy	Average value 0.0271 µm/yr	Temperature range 25 °C to 90 °C
Stainless steel Type 316L	Median value 0.003 µm/yr	30 °C, fresh water

- In simulated acidic water, corrosion rate of borated stainless steel is 3.5 µm/year; however, localized corrosion also occurred†

* Screening Analysis of Criticality Features, Events, and Processes for License Application. ANL-DSO-NU-000001 Rev 00C. October 2007.

† Fix, D.V., J.C. Estill, L.L. Wong, and R.B. Rebak. "General and Localized Corrosion of Austenitic and Borated Stainless Steels in Simulated Concentrated Ground Waters." PVP-Vol. 483, Transportation, Storage, and Disposal of Radioactive Materials. San Diego, California. ASME. 2004.

Literature Reported General Corrosion Rates of Borated Stainless Steel at Different Environments (Continued)

- In solution {[Cl^-] = 0.004 m, [F^-] = 0.001 m, [NO_3^-] = 0.0025 m, pH = 7} at 60 °C*
  - Aerated after 1 week from polarization: 0.080 µm/yr for 304B6 stainless steel
  - N_2 purged after 48 hours from polarization measurement: 0.221 µm/yr for 304B4 stainless steel, 0.427 µm/yr for 304B5, and 0.464 µm/yr for 304B6
- Corrosion rates reported in literature in harsh solutions for Stainless Steel Type 304 (0.3% B) ranged from 3 – 60 µm/yr †

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* Lister, T.E., R.E. Mizia, A.W. Erickson, and T.L. Trowbridge. "Electrochemical Corrosion Testing of Neutron Absorber Materials." Idaho National Laboratory. INL/EXT-06-11772. Rev. 1. May 2007.

† Aqueous Corrosion Rates for Waste Package Materials. Table 6-7. ANL-DSD-MD-000001. Rev 01. October 2004. (Original source: Cole, H.S. "Corrosion of Stainless Steel Type 304 Alloyed with Boron or Gadolinium by Plant Process Solutions Containing HNO_3 and HF." Idaho Falls, Idaho: Idaho National Engineering Laboratory. ICP-1097. 1976.)

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Summary

- Boron in borated stainless steel forms secondary phase particles with Fe and Cr
- Borated stainless steels were less resistant to corrosion than the regular austenitic materials without boron addition
- In chloride solution, borated stainless steel is susceptible to localized corrosion, mostly in the regions surrounding the secondary phase particles due to Cr-depletion
- Boron was not observed to dissolve preferentially, but it may disintegrate from the material due to localized corrosion at surrounding areas

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Summary (Continued)

- The general corrosion rate varies in the range of micrometers/year to tens of nanometers/year depending on the test environment and test duration

- The reported general corrosion rate may not be fully representative of general corrosion due to the occurrence of localized corrosion along with general corrosion

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Acknowledgment and Disclaimer

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