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Effects of Irradiation on Fatigue Life

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Public Meeting on Environmentally Assisted Fatigue (EAF)
Research and Related ASME Activities
Nuclear Regulatory Commission Headquarters
September 25, 2018

Background

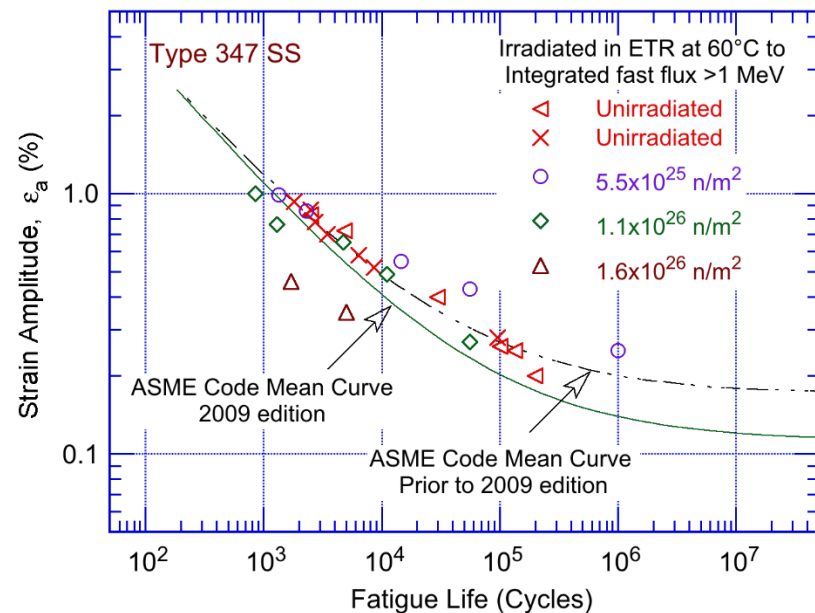
- Irradiation effects are not considered in ASME Section III fatigue evaluations
- Little current experimental data on irradiation effects for nuclear materials under conditions representative of commercial light-water reactors
 - Most data dates to mid-1970s or earlier
 - Much of the irradiation conducted in fast flux reactors at either higher ($> 400^{\circ}\text{C}$) or lower ($< 100^{\circ}\text{C}$) temperatures than service conditions
- Changes in microstructure resulting from irradiation have been observed but not correlated with fatigue life
 - Microstructure and microchemistry changes
 - Cavities and He bubble formation
- Some fatigue tests have been performed
 - Fatigue crack growth rate (FCGR)
 - Fatigue life (i.e., $\epsilon - N$)

Effects of Irradiation on FCGR

- Experimental Breeder Reactor II (EBR-II) Tests
 - Type 304 & 316 SS irradiated at 410°C to 1.2×10^{22} n/cm² and tested at 427°C and 593°C
 - 427°C results
 - CGRs in irradiated specimens up to factor of 2 higher for $\Delta K < 44$ MPa√m
 - CGRs in irradiated specimens lower for $\Delta K > 44$ MPa√m
 - 593°C results
 - Opposite trends compared to the 427°C results
- Advanced Test Reactor (ATR) Tests
 - Type 304 and 316 SS irradiated at 288°C to 1.8×10^{21} n/cm² and tested at 427°C.
 - Results
 - CGRs in irradiated specimens 2 – 4 times lower
- No significant deleterious effects of irradiation in these tests and improved resistance to fatigue cracking observed under some conditions

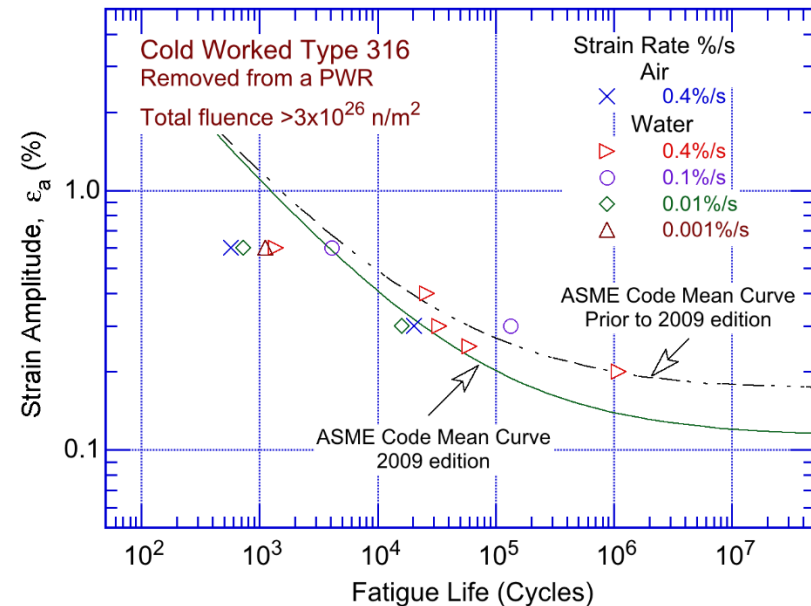
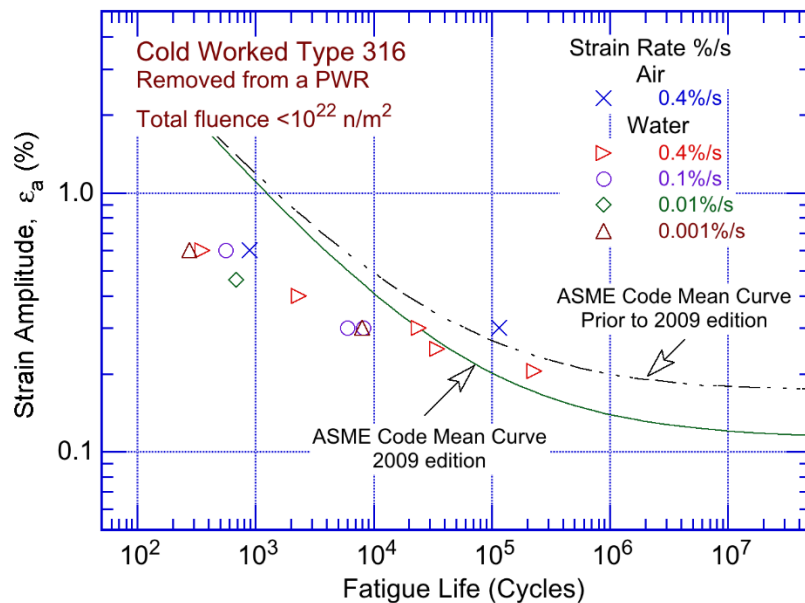
Effects of Irradiation on $\epsilon - N$

- Engineering Test Reactor (ETR) Tests
 - Type 347 SS irradiated at 60°C to 5.5×10^{25} n/m² and above
 - Tested at room temperature
- Low strain amplitudes ($\epsilon < \approx 0.35\%$): Irradiation appears to increase fatigue life
- High strain amplitudes: Irradiation appears to decrease fatigue life



Effects of Irradiation on $\epsilon - N$, cont.

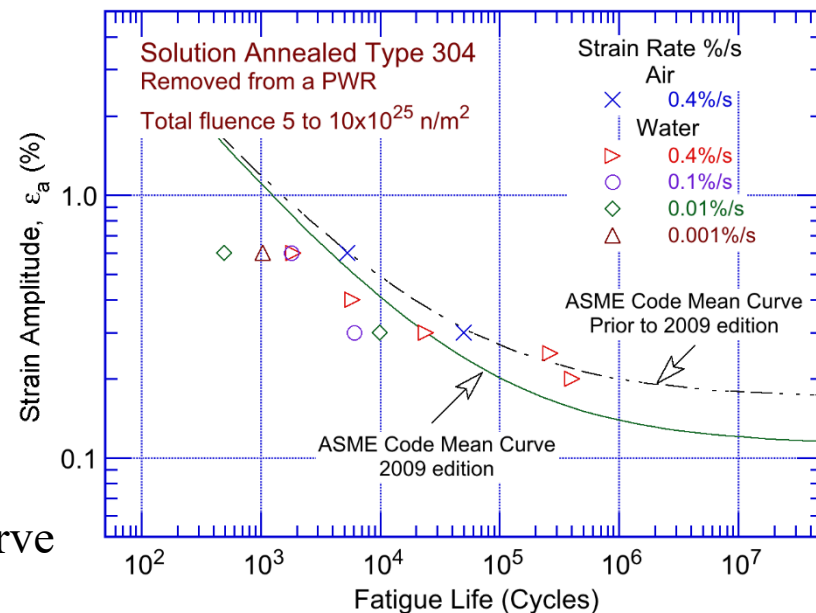
- Tests on CW Type 316 SS Tubes Removed from PWR Plant
 - Irradiated to fluences $< 10^{22}$ n/m² to $> 3 \times 10^{26}$ n/m²
 - Tested in air and PWR-simulated water at 325°C and various strain rates
 - No baseline unirradiated tests for comparison



- Fatigue life for tube specimens decreased by approximately 1.5
- $\epsilon - N$ relationship of irradiated material appears flatter than the ASME Code mean curve

Effects of Irradiation on $\epsilon - N$, cont.

- Tests on Solution Annealed Type 304 SS Bars Removed from PWR Plant
 - Irradiated to fluences from 0.5 to 1×10^{26} n/m²
 - Tested in air and PWR-simulated water at 325°C and various strain rates
 - No baseline unirradiated tests for comparison
- As with CW 316 results, irradiated life curve appears flatter than ASME mean curve
- Implication is that irradiation may increase fatigue life at low strain amplitudes while decreasing life at higher strain amplitudes



Summary

- Effects of irradiation on fatigue crack growth rates (CGRs)
 - Conclusive trends cannot be established due to limited LWR-representative data
 - No significant increase in FCGRs due to irradiation observed in existing test data
 - Decreases in FCGRs due to irradiation observed under some conditions
- Effects of irradiation on fatigue life (i.e., $\epsilon - N$)
 - Conclusive trends cannot be established due to limited LWR-representative data
 - However, consistent trends have been observed in existing test data
 - Decreases in fatigue life at higher (i.e., > 0.35 to 0.6%) strain levels
 - Increases in fatigue life at low (i.e., < 0.35 to 0.6%) strain levels
 - Trends appear consistent with material changes caused by irradiation
 - Hardening causes increased tensile strength, leading to increased high cycle fatigue resistance
 - Reduced ductility could lead to decreases in low-cycle fatigue life

Discussion - Next Steps

- Research
 - Effects of irradiation on fatigue life are one of the least understood of all potential contributing factors to fatigue life
 - Information on any additional past, current, or planned research in this area would be important
 - ☐ Relevance/feasibility of using FCR portion of IASCC testing as additional data.
- Implications
 - Any deleterious effects of irradiation on fatigue life will increase with operating time
 - Issue is only relevant to a limited scope of reactor internal components
 - ☐ Scoping would be useful to identify components of interest
- Potential resolution
 - Limited test program would be useful in confirming/predicting significant trends
 - ☐ Testing representative materials under LWR conditions
 - ☐ Initial focus should be on low-cycle fatigue effects and the transition between low-cycle and high-cycle regimes.
 - Other thoughts?