Effects of Irradiation on Fatigue Life

Robert Tregoning

Nuclear Regulatory Commission

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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^{o}C) or lower (< 100^{o}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., ε – N)

Effects of Irradiation on FCGR

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- Experimental Breeder Reactor II (EBR-II) Tests
  - Type 304 & 316 SS irradiated at 410°C to $1.2x10^{22}$ n/cm^2 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 $1.8x10^{21}$ n/cm^2 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 ε – N

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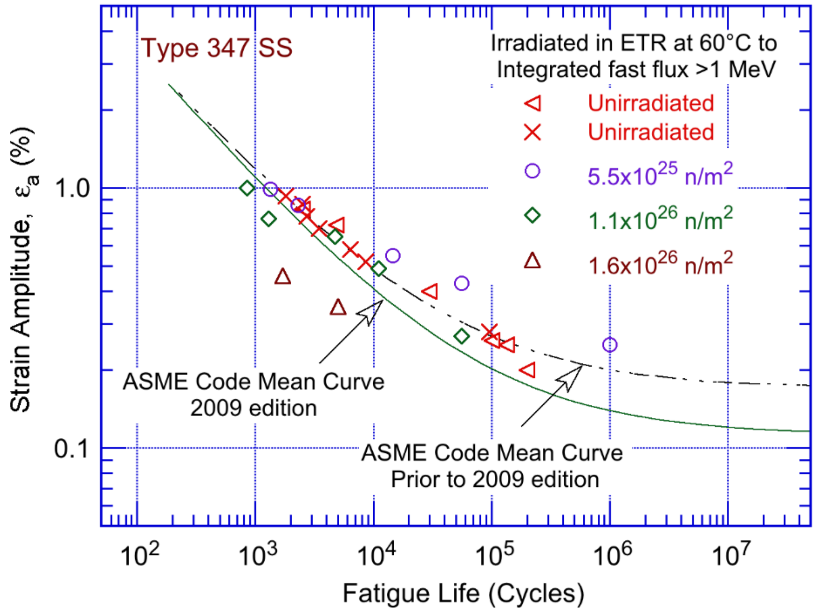
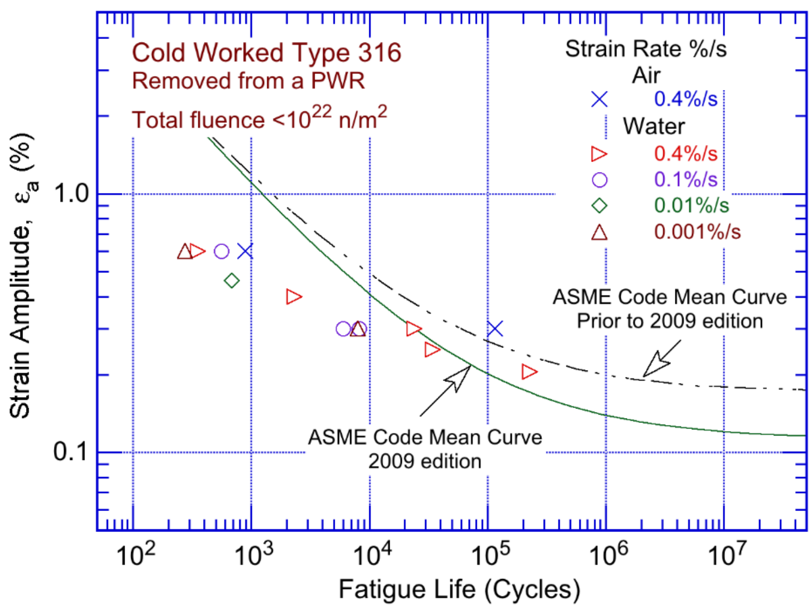
- Engineering Test Reactor (ETR) Tests
  - Type 347 SS irradiated at 60°C to 5.5×10^{25} n/m² and above
  - Tested at room temperature

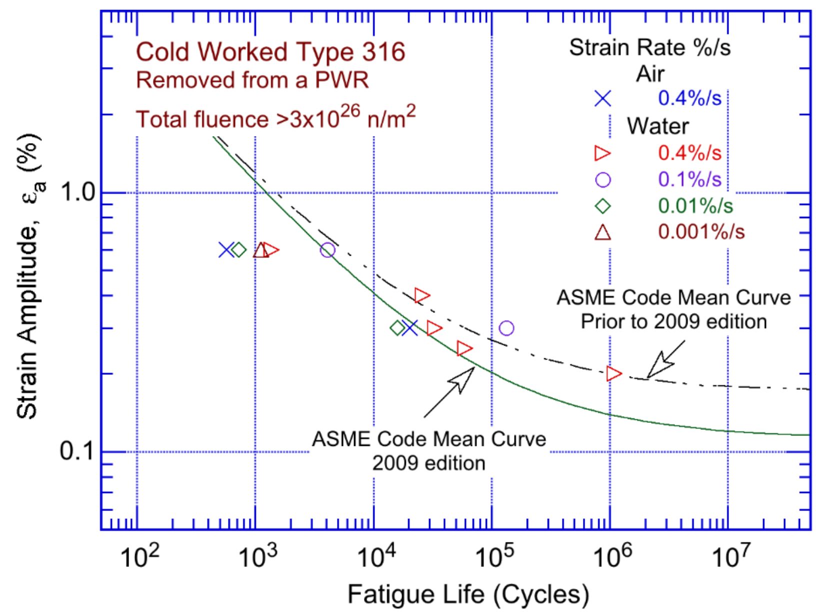


- Low strain amplitudes (ε < ≈0.35%): Irradiation appears to increase fatigue life
- High strain amplitudes: Irradiation appears to decrease fatigue life

Effects of Irradiation on ε – N

- Tests on CW Type 316 SS Tubes Removed from PWR Plant
  - Irradiated to fluences < 10^{22} n/m² to > $3x10^{26}$ n/m²
  - Tested in air and PWR-simulated water at 325°C and various strain rates
  - No baseline unirradiated tests for comparison

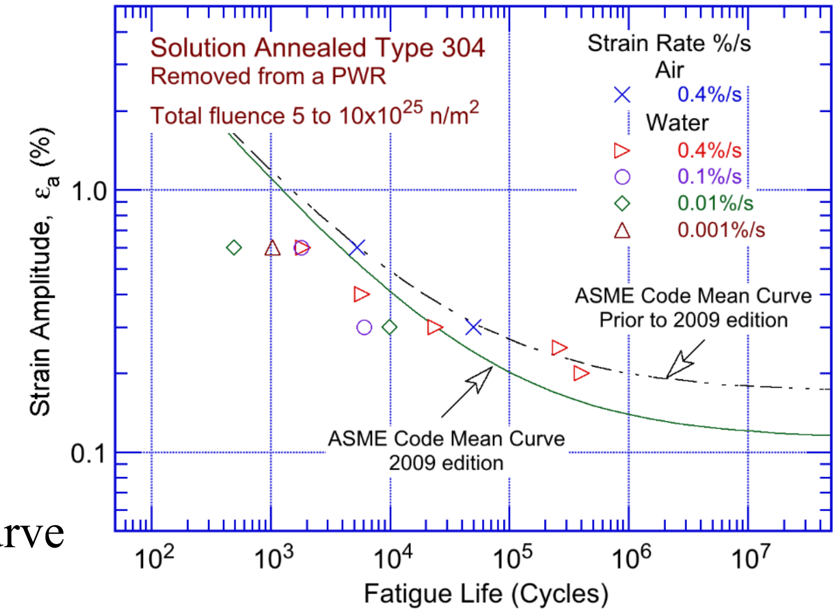




- Fatigue life for tube specimens decreased by approximately 1.5
- ε – N relationship of irradiated material appears flatter than the ASME Code mean curve

Effects of Irradiation on ε – N

- Tests on Solution Annealed Type 304 SS Bars Removed from PWR Plant
  - Irradiated to fluences from 0.5 to $1x10^{26}$ n/m^2
  - 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

Conclusions

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- Effects of irradiation on fatigue crack growth rates
  - 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., ε – 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
- Testing of representative materials and LWR conditions could be used to characterize the effects of irradiation. Initial focus should be on low-cycle fatigue effects and the transition between low-cycle and high-cycle regimes.