How Irradiation Promotes Intergranular Stress Corrosion Crack Initiation

P. Wang, S. Raiman, G. Was
University of Michigan

NSUF Annual Program Review, April 18, 2024

Objective

- Facilities for IASCC Study
- Introduction
- Impact of IASCC on Nuclear Reactor Components
- Historical Context and Characterization of IASCC
- Mechanisms of IASCC
- Implications and Future Directions

NSUF Facilities

Irradiation Materials Testing Lab (IMTL)

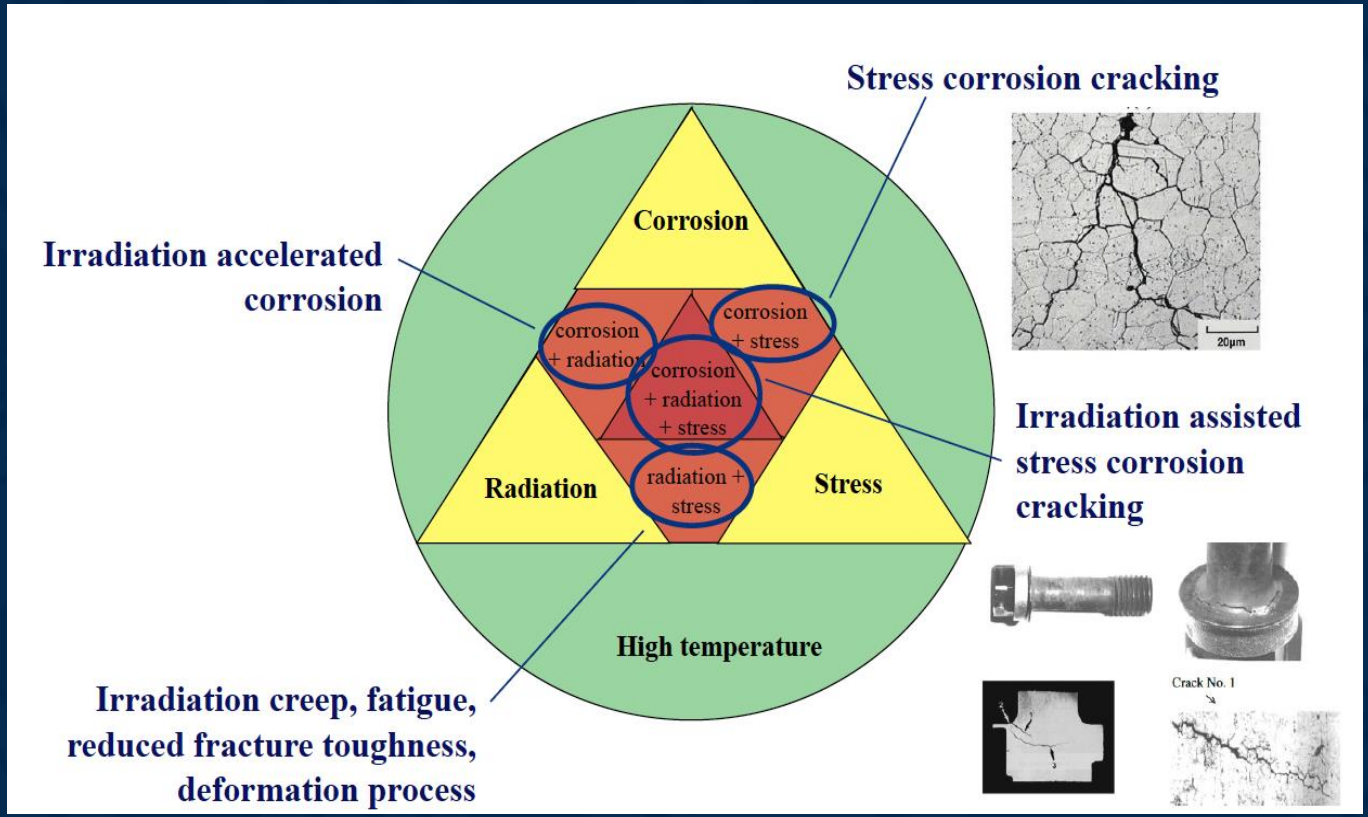
- 5 CERT/CGR systems (SS316L & Inconel 625 Autoclaves)
- Supercritical Water or LWR Environments (PWR, NWC, HWC)
- Multiple Specimen CERT Tests
- Single Specimen CGR Tests with DCPD measurement

MiHTEE Lab
Materials in High Temperature Extreme Environments

High Temperature Corrosion Lab (HTCL)

- 5 CERT systems (Ti, SS304 and Inconel 625 Autoclaves)
- Supercritical Water or LWR Environments (PWR, NWC, HWC) or Steam
- Single/Multiple Specimen CERT Tests
- Long-term Exposure Tests
- 1 Creep system (SS316L)

NSUF Nuclear Science User Facilities


Stress corrosion cracking
Irradiation accelerated corrosion
Corrosion
corrosion + radiation
corrosion + stress
corrosion + radiation + stress
radiation + stress
Radiation
Stress
High temperature
Irradiation assisted stress corrosion cracking
Irradiation creep, fatigue, reduced fracture toughness, deformation process
20μm
Crack No. 1

Impact of IASCC on Nuclear Reactor Components

- Irradiation assisted stress corrosion cracking (IASCC) is responsible for accelerating the intergranular cracking of austenitic alloys in reactor cores.
- IASCC occurs in all light water reactor (LWR) environments in over 20 different core components from over 10 stainless steel and Ni-based alloys
- Large plant-to-plant and heat-to-heat differences are observed in the occurrence of IASCC.

- The process by which IASCC occurs has remained elusive due to the synergistic nature of its occurrence, requiring an irradiated microstructure, high temperature water (corrosive), and application of stress.

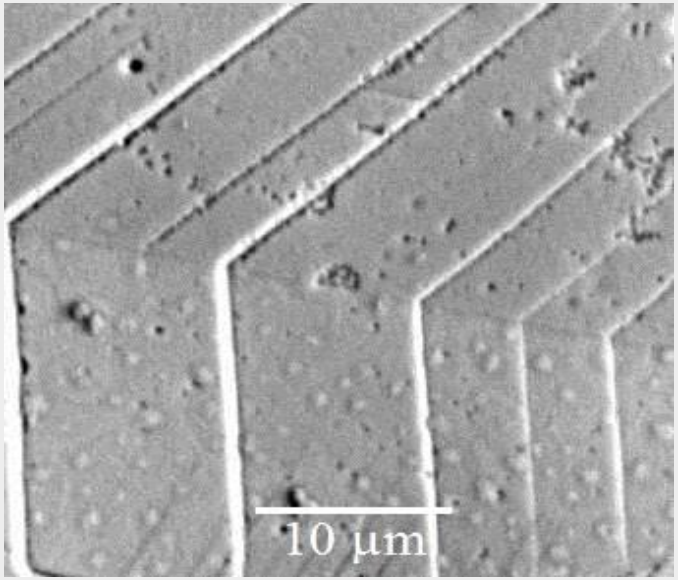
Historical Context and Characteristics of IASCC

Three processes that hold the key to the IASCC mechanism:

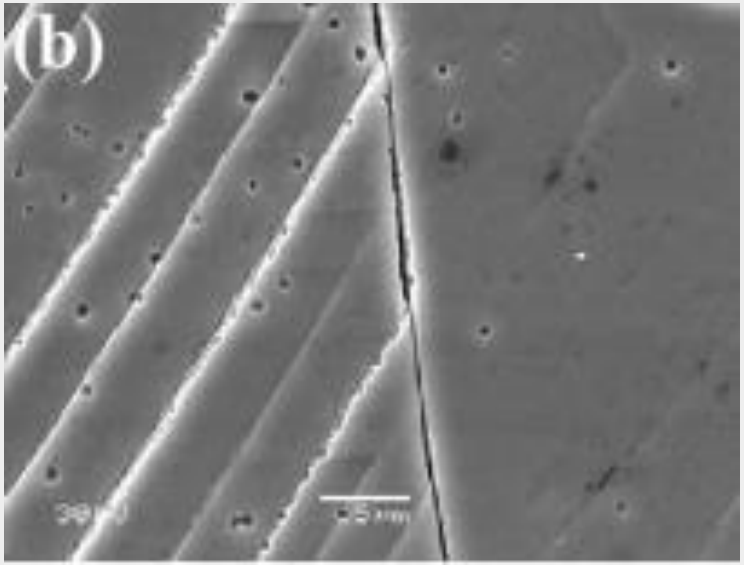
1) Irradiated alloy deform in a different manner from the non-irradiated condition
2) GBs in irradiated austenitic alloys oxidize when exposed to high temperature water
3) Si segregation to the grain GB oxidizes when exposed to high temperate water

Deformation in irradiated alloys is heterogeneous in the form of dislocation channels

Continuous

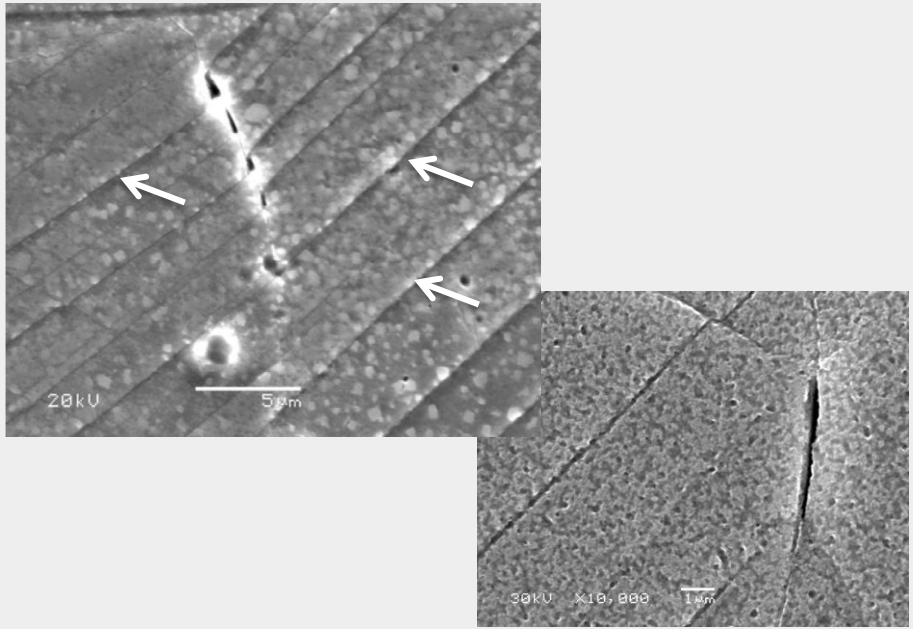


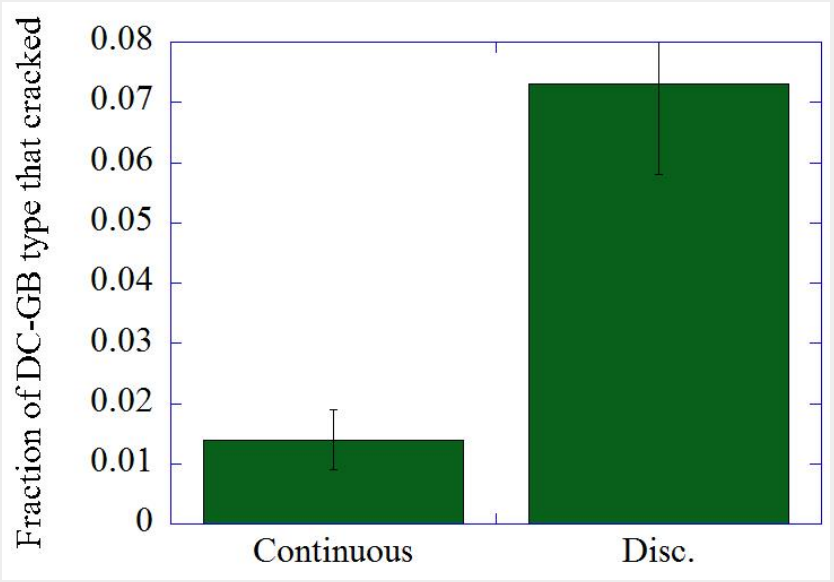
Discontinuous



M. McMurtrey, et al. MSE. A 528(2011)3730

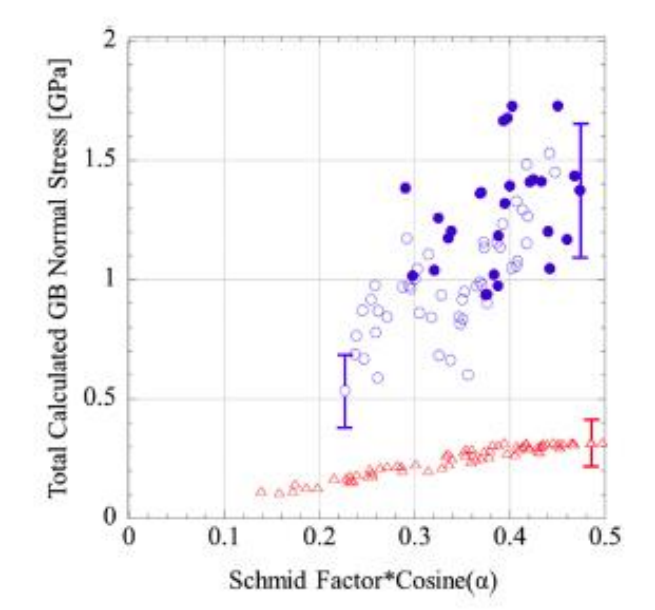
IG cracks occur preferentially at DC-GB sites





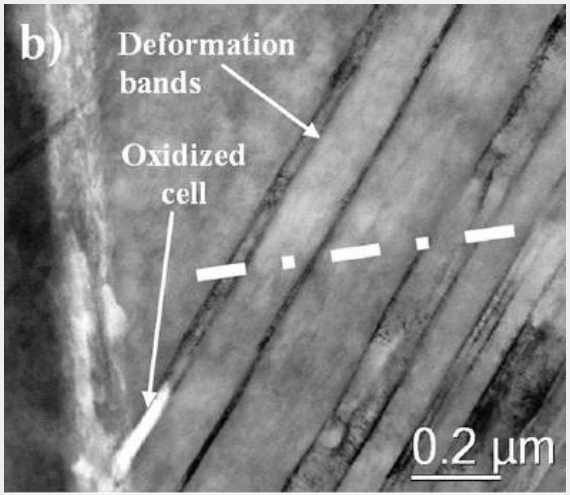
M. McMurtrey, et al. MSE. A 528(2011)3730

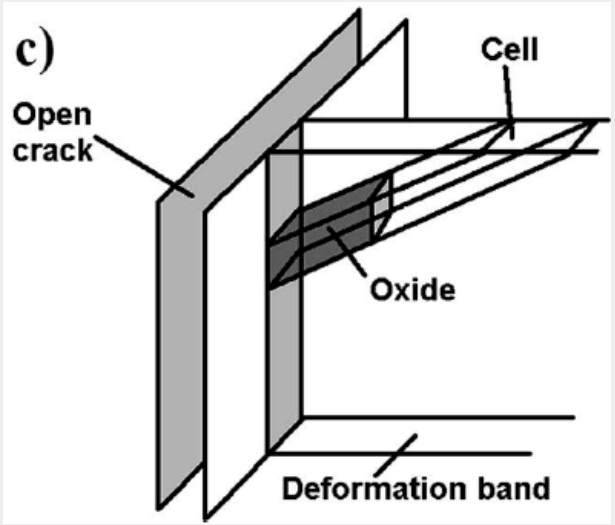
Normal stress at discontinuous DC-GB sites is much higher than at continuous DC-GB sites and cracking only occurs at the former



D. Johnson et al. Acta Mater 170(2019)166

Oxidation of deformation bands in CW 304SS

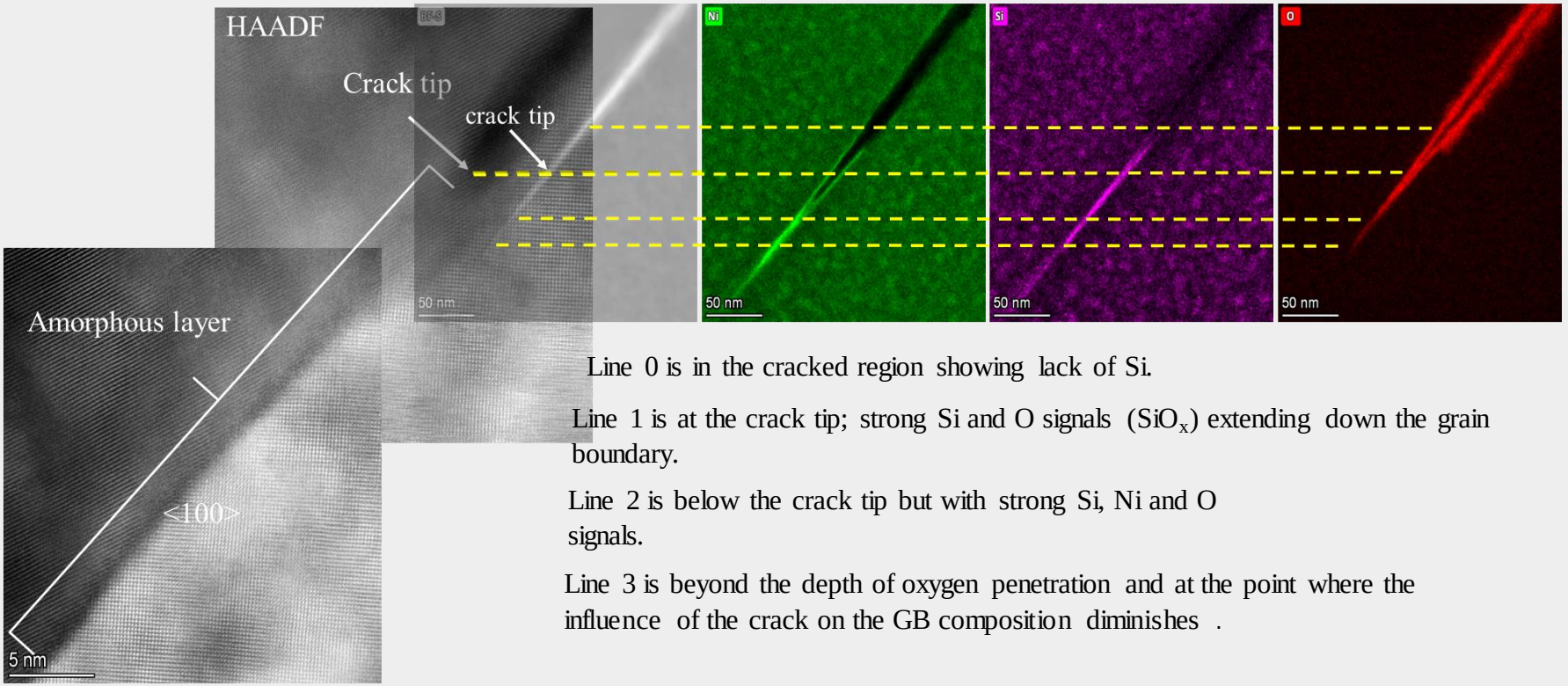




Proposed that SCC crack advance occurs at a rate that is governed by the role of deformation bands as stress concentrators and their shearing, as controlled by the inward diffusion of oxygen.

Lozano-Perez et al. Acta Mater 57 (2009) 5361

A potential contributing factor: GB enrichment of Si



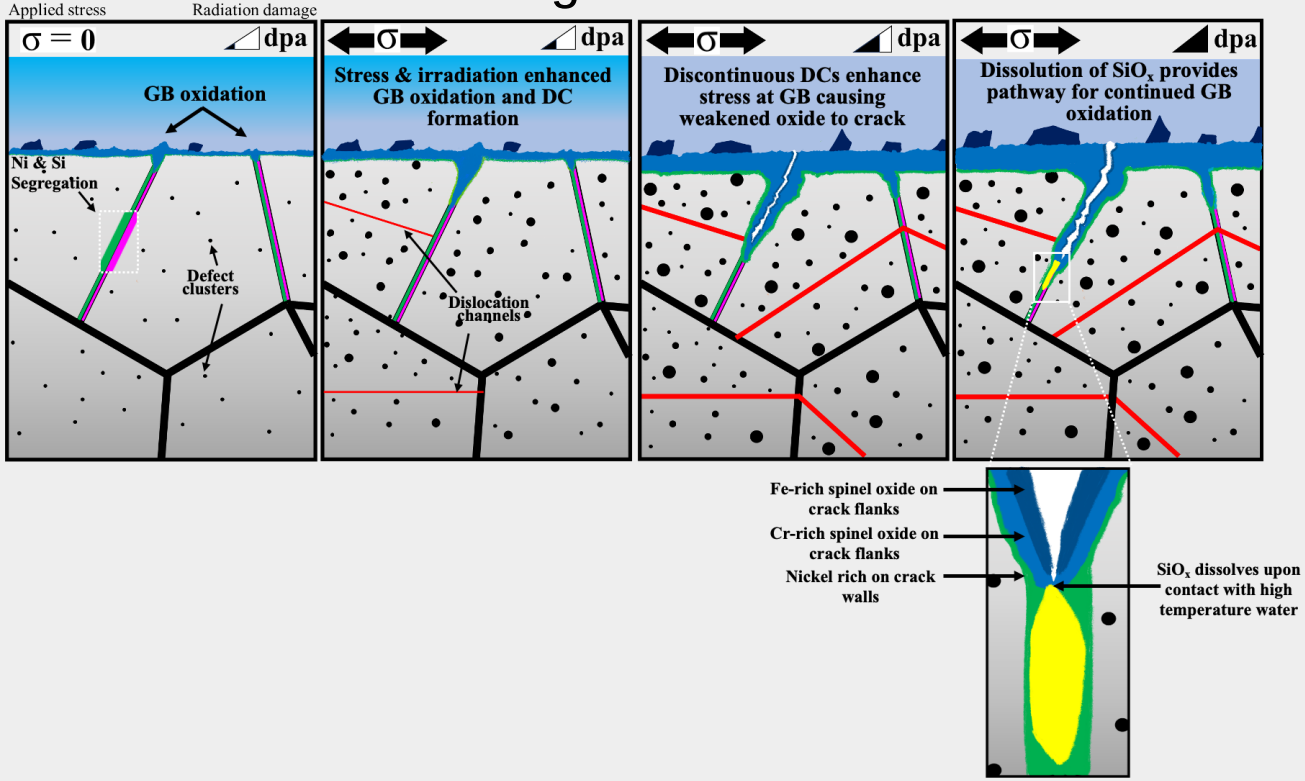
Line 0 is in the cracked region showing lack of Si.

Line 1 is at the crack tip; strong Si and O signals (SiO_x) extending down the grain boundary.

Line 2 is below the crack tip but with strong Si, Ni and O signals.

Line 3 is beyond the depth of oxygen penetration and at the point where the influence of the crack on the GB composition diminishes .

A new understanding of the mechanism of IASCC



MiHTEE Lab (MiHTEE-LAB@umich.edu)