Grain-boundary embrittlement in highly irradiated 15-15Ti austenitic steel

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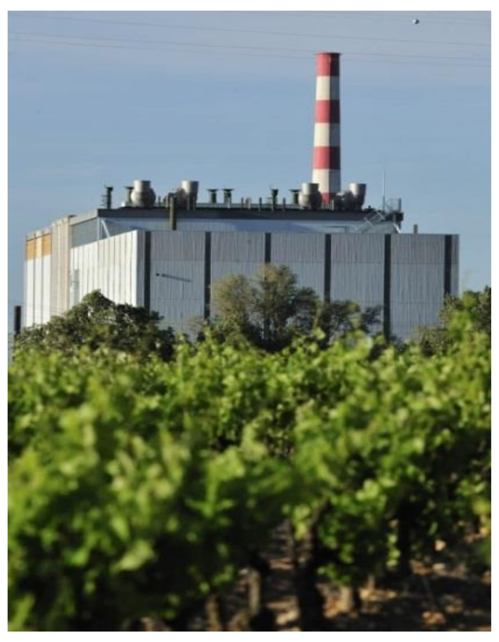
Introduction

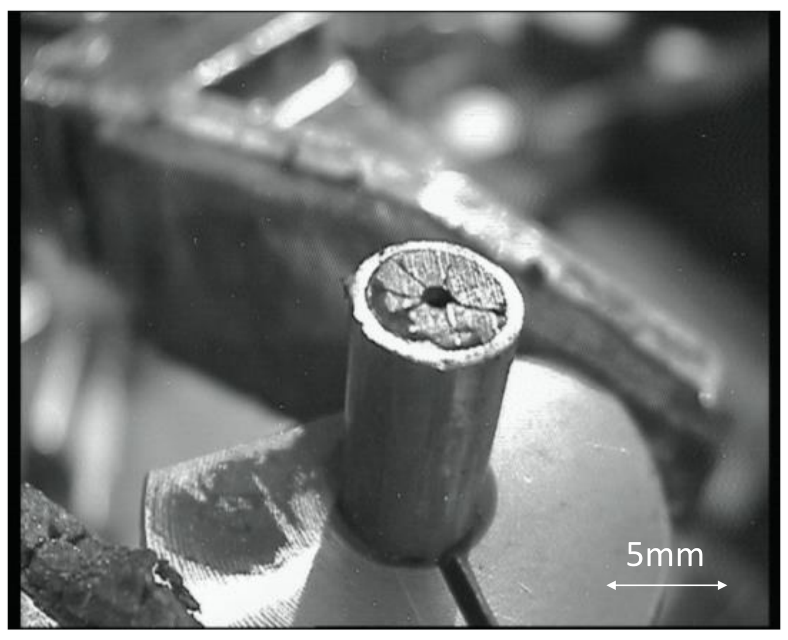
- Fuel cladding material for GEN-IV SFR reactor
- Optimized 15-15Ti austenitic steel designed to minimize irradiation swelling

Composition in wt%

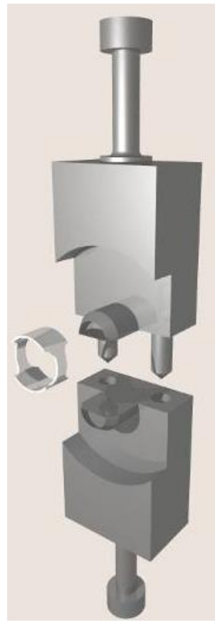
Ti	Si	C	P	Mn	Mo	Ni	Cr
0,50	0,95	0,085	0,007	1,50	1,46	14,8	14,9

- 20% cold working after annealing treatment
- Fuel pin irradiated in Phénix SFR (110 dpa max)
- PIE performed at CEA/LECA & CEA/LECI


Phénix experimental fast reactor



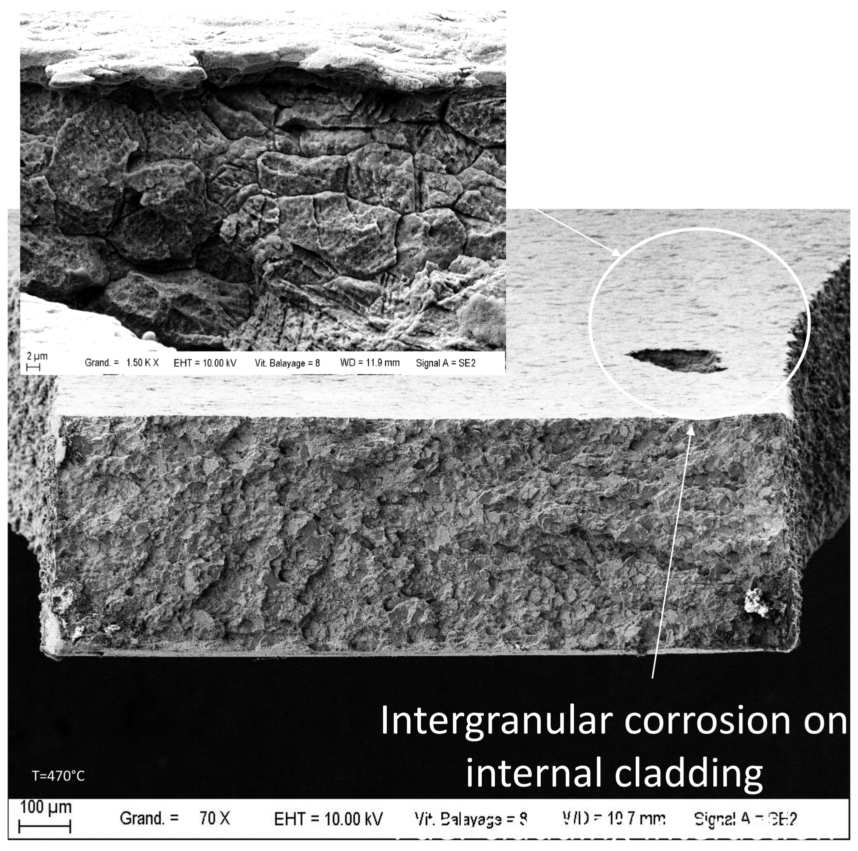
Sample cutting CEA/LECA


Ring tensile test CEA/LECI

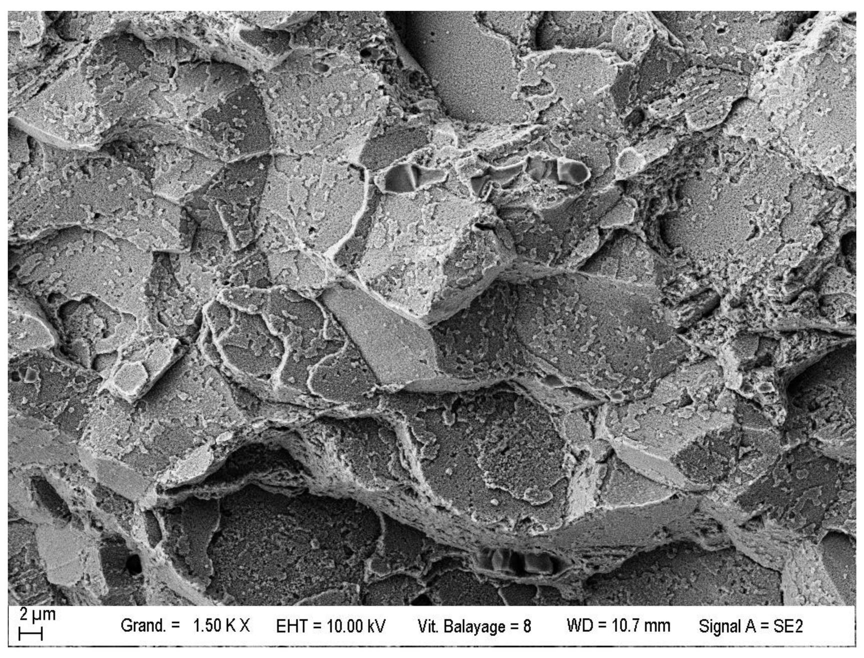
- Irradiation temp. : 470°C
- Dose : 93 dpa
- Swelling : 4.4%
- Tensile properties 20°C :
  - *Total Elong. = 0.3%*
  - *$YS_{0.2}$ = 883 MPa*
  - *UTS = 908 MPa*

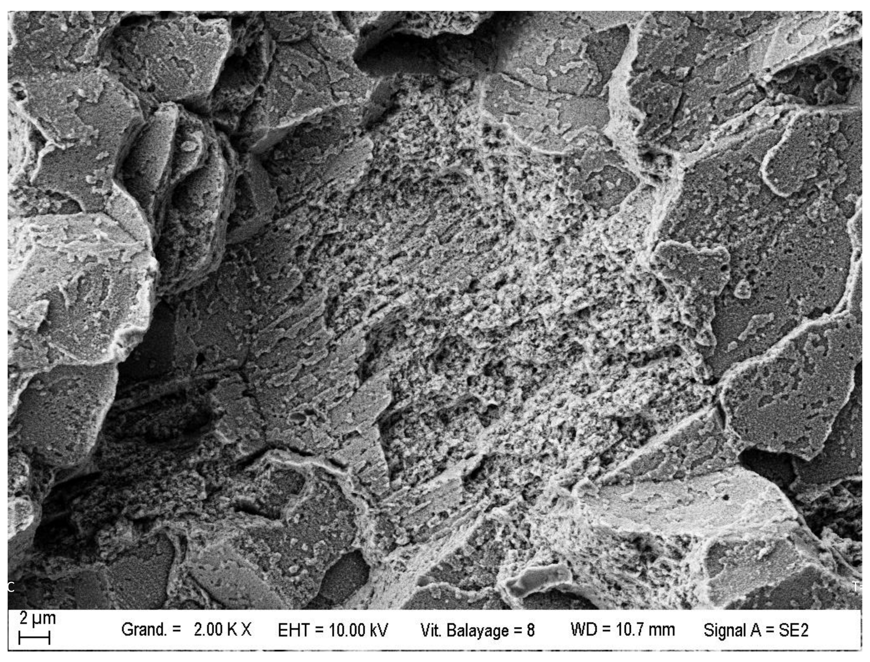
→ Low ductililty

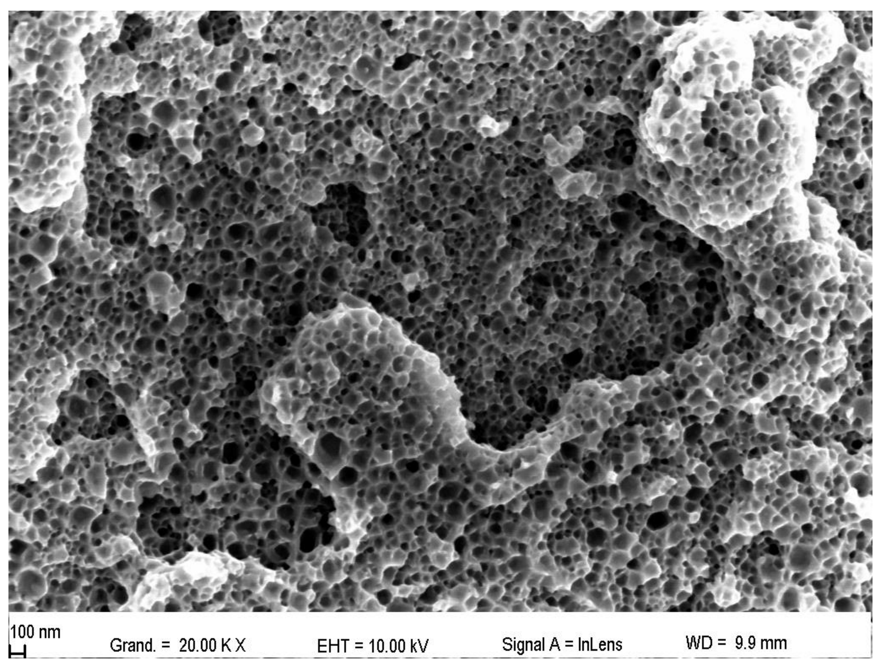
Fractography after ring tensile test at 20°C



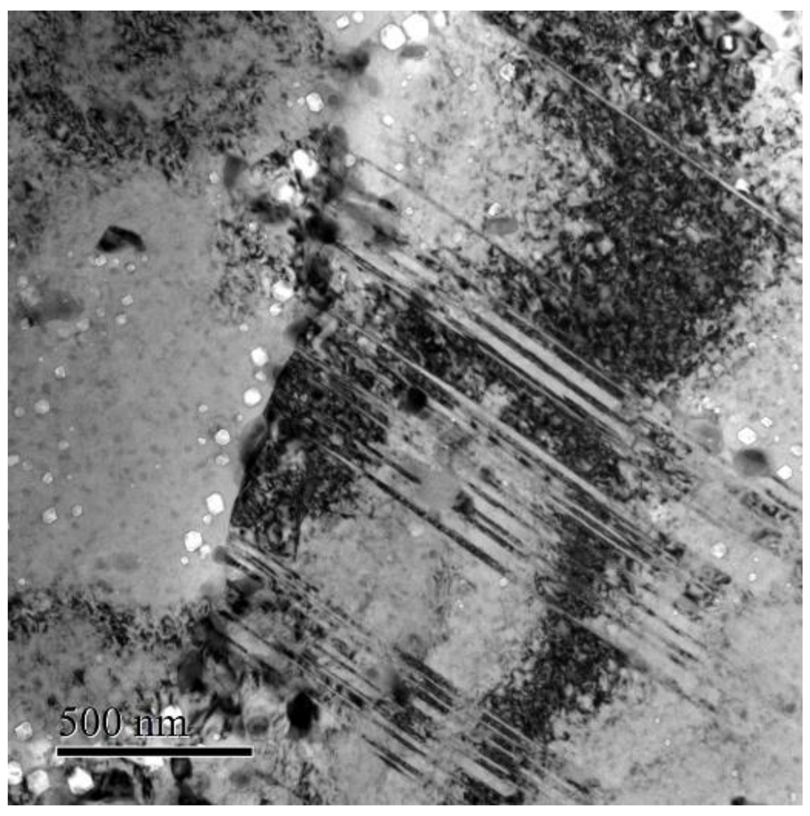
General overview


Intergranular rupture with nanodimples and precipitates at GB

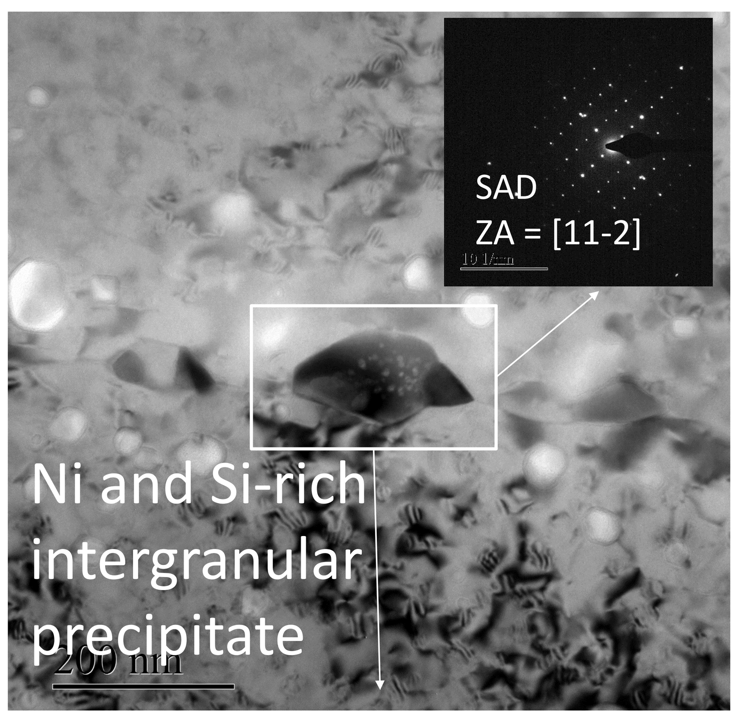

Transgranular fracture high local swelling

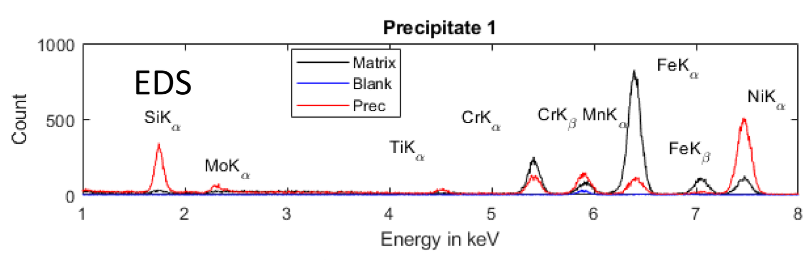

Nanodimples at grain boundary T_{irr}=450°C

Transmission Electron Microscopy

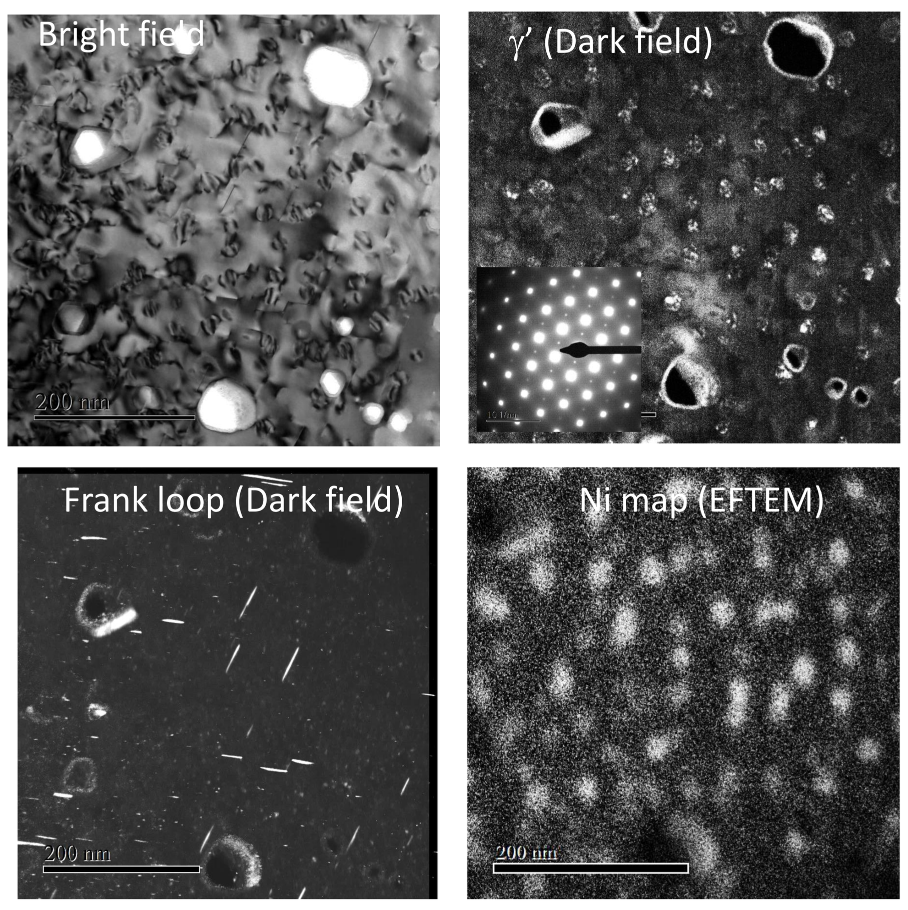


Cavities around Grain Boundary

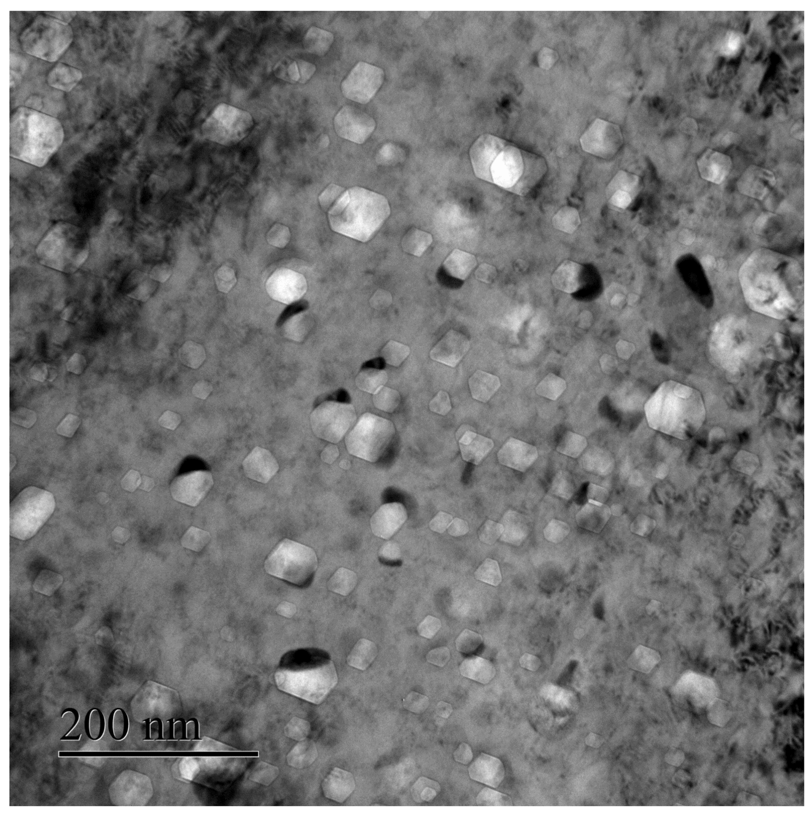




Intergranular precipitate
SAD+EDS ⟹ G phase



Matrix hardening : irradiation defects
Cavities – Frank loops, γ'



Cavities inside grain
Attached to precipitates (G phase)

Discussion on embrittlement mechanisms

- Low ductility observed in tensile test :
  - Segregation of Si and Ni and precipitation (G phase) at grain boundary
  - Low average swelling (~4,4%) but high local swelling near grain boundaries
  - Matrix irradiation hardening (irradiation defects : interstitial loops, cavities and precipitation γ')
  - Suspected Fuel-cladding interaction at low temperature <500°C