Karlsruhe Institute of Technology

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Dislocation loop evolution upon annealing of neutron-irradiated RAFM steel

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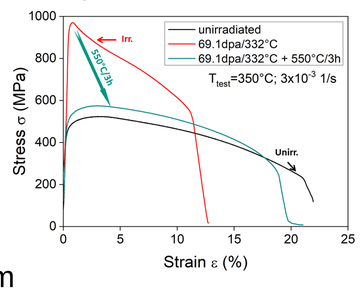
Motivation and Objective

- Reduced-activation ferritic/martensitic (RAFM) steels
  - Withstand harsh working environment
  - Excellent resistance against high dose irradiation swelling and high temperature embrittlement
- Neutron irradiation
  - Degradation of mechanical properties

  → Characterization of irradiation-induced defects
- Post-irradiation annealing (PIA)
  - Recovery of mechanical properties

  → Understand the underlying recovery mechanism

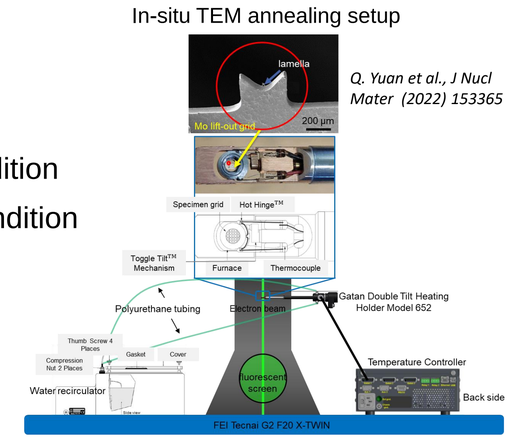
E. Gaganidze, C. Petersen KIT-SR 7596, 2011



Methodology

- TEM sample preparation at Fusion Materials Laboratory (FML)
  - Electro-polishing
  - Focused-ion beam (FIB) polishing
- Quantitative TEM characterization
  - Kinematical bright-field (KBF) condition
  - Weak-beam dark-field (WBDF) condition
  - HAADF-STEM
- Post-irradiation annealing (PIA)
  - In-situ TEM thin-foil annealing
  - Isothermal thick-foil annealing

In-situ TEM annealing setup



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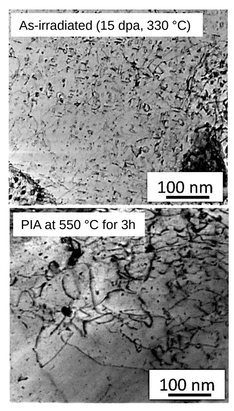
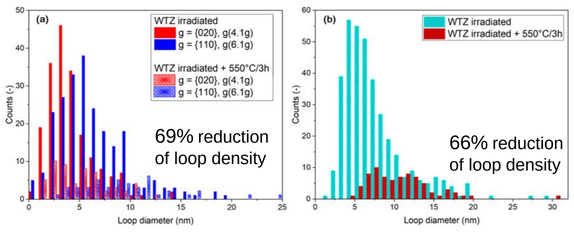
Results

Dislocation loop evolution

- PIA at 550 °C for 3 hours results in a reduction of the dislocation loop density and formation of dislocation networks
  - Homogenous distribution of the dark-contrast dislocation loops in the as-irradiated condition
  - Significantly lower dislocation loop density after PIA
  - Frequent observations of dislocation lines/networks



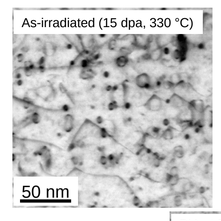
A. Chuanhan et al., J Nucl Mater (2021) 152863



Dislocation loops size distributions for the as-irradiated (15 dpa, 330 °C) and PIA (550 °C/3 h) EUROFER97 samples estimated via (a) WBDF and (b) HAADF-STEM techniques

Dislocation loop coarsening

- Annealing at 550 °C for 1 hour
  - Dislocation loop coarsening
  - Dislocation loop shape evolution



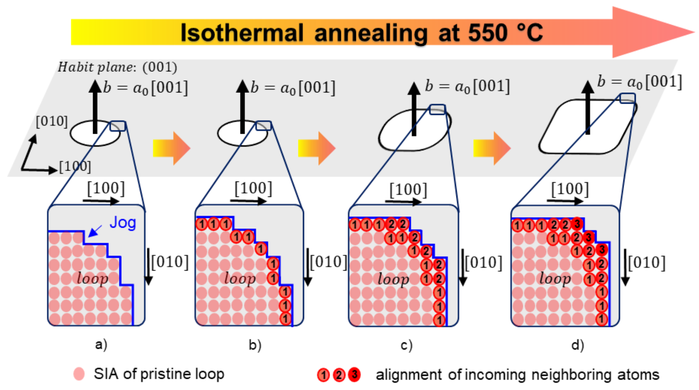
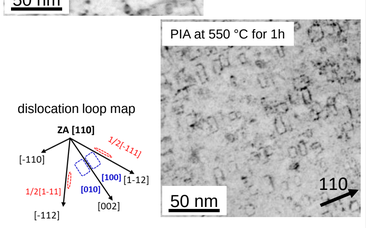


Illustration of dislocation loop coarsening with shape evolution



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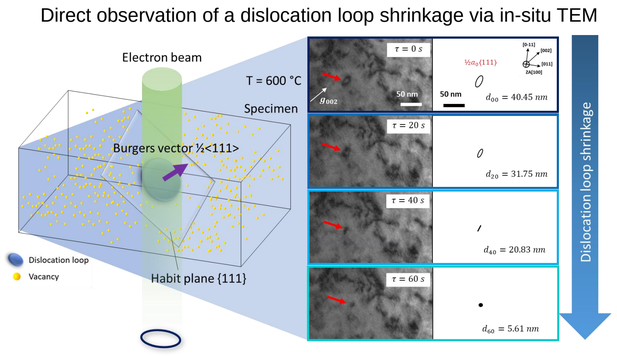
Dislocation loop shrinkage

- In general, the vacancy flux occurring down the concentration gradient defines the annealing behaviour of dislocation loops.
- Annealing kinetics of the loop is dictated by:
  - Influence of neighbouring microstructure
  - Influence of loop type
  - Influence of alloying elements segregation
  - Influence of free surface

Direct observation of a dislocation loop shrinkage via in-situ TEM



Q. Yuan et al., J Nucl Mater (2020) 152401

Dislocation tangle/network formation

- Annealing at 550 °C for longer time (2 and 3 hours)
  - Formation of large irregular shape dislocation loops
  - Formation of dislocation tangles/networks

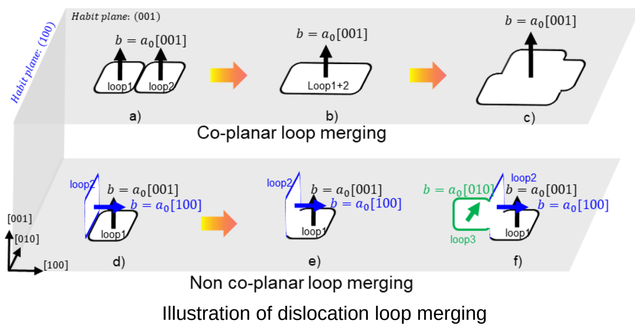


Illustration of dislocation loop merging

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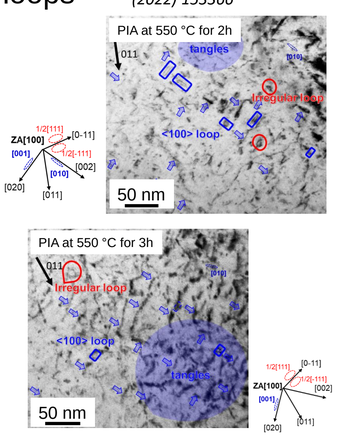

Conclusions

- PIA at 550 °C results in dislocation loops shrinkage/annihilation as well as their coarsening/merging phenomena.
- The annealing kinetics of dislocation loop is influenced by loops neighbouring microstructure, loop type, alloying elements segregation and surface effect.
- Dislocation tangles/networks were developed via the merging and/or annihilation of dislocation loops with continued annealing.

Outlooks

- Real-time investigations of dislocations and defects in irradiated materials under applied strain via in-situ TEM straining
- Understanding the underlying deformation and damage mechanisms at room and elevated temperature
- Investigation of alloying elements segregation on dislocation loops

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EUROfusion

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