NME 2025

A study on Irradiation and Non-Isothermal Creep-Fatigue Behavior of Eurofer97 Steel Based on a Multi-Mechanism Coupling Model

Paper ID NME1559

GHENT UNIVERSITY

Jianxin Liu, Magd Abdel Wahab
Soete Laboratory, Faculty of Engineering and Architecture, Ghent University, 9000, Ghent, Belgium

Introduction

Future fusion reactors will subject Eurofer97 steel to extreme conditions, impacting its Low Cycle Fatigue(LCF). Existing models struggle to predict the coupled effects of temperature, irradiation, and specimen size. This research develops a unified constitutive model to simultaneously address these coupled influences on Eurofer97's LCF behavior and lifetime, vital for reactor integrity.

Methods

The research method centers on developing a viscoplastic-damage constitutive model. This model aims to systematically simulate the LCF behavior and lifetime of Eurofer97 steel.

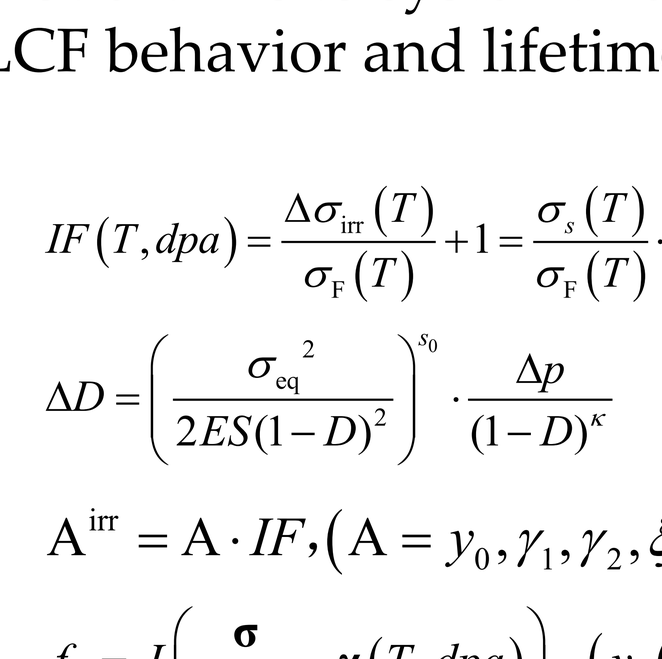
$$IF\left(T,dpa\right)=\frac{\Delta\sigma_{\mathrm{irr}}\left(T\right)}{\sigma_{\mathrm{F}}\left(T\right)}+1=\frac{\sigma_{s}\left(T\right)}{\sigma_{\mathrm{F}}\left(T\right)}\cdot\sqrt{1-\exp\left(-\frac{dpa}{dpa_{0}\left(T\right)}\right)}+1$$

$$\Delta D=\left(\frac{\sigma_{\mathrm{eq}}{}^{2}}{2ES(1-D)^{2}}\right)^{s_0}\cdot\frac{\Delta p}{(1-D)^{\kappa}}$$

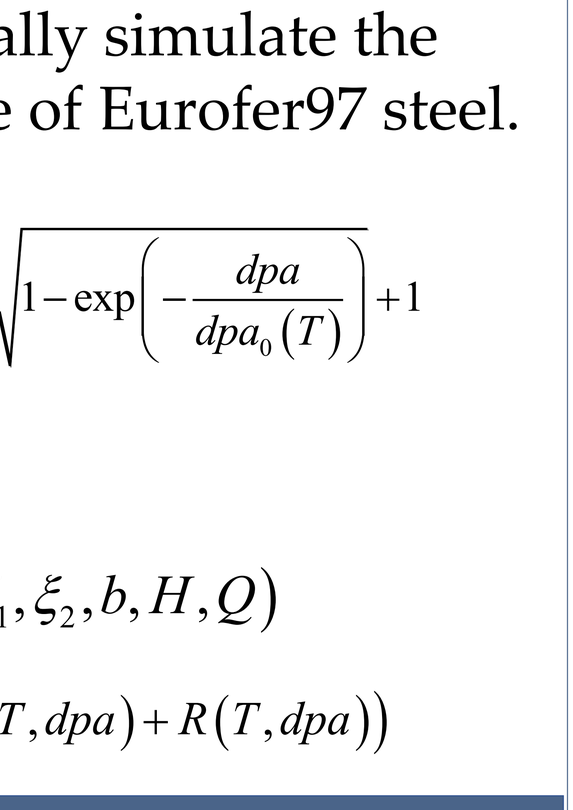
$$\mathrm{A}^{\mathrm{irr}}=\mathrm{A}\cdot IF,\left(\mathrm{A}=y_0,\gamma_1,\gamma_2,\xi_1,\xi_2,b,H,Q\right)$$

$$f_y=J\left(\frac{\boldsymbol{\sigma}}{1-D}-\boldsymbol{\chi}\left(T,dpa\right)\right)-\left(y_0\left(T,dpa\right)+R\left(T,dpa\right)\right)$$

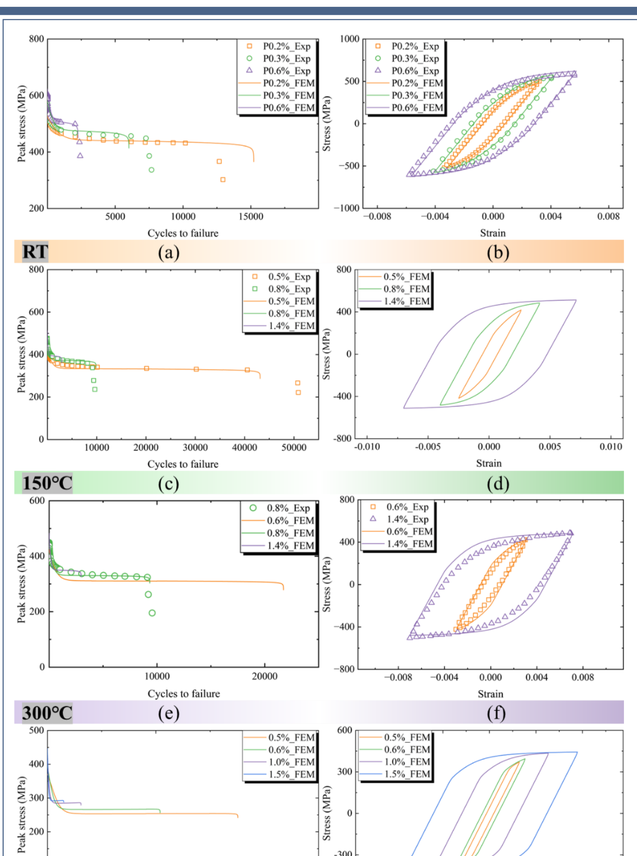
Graphics / Images



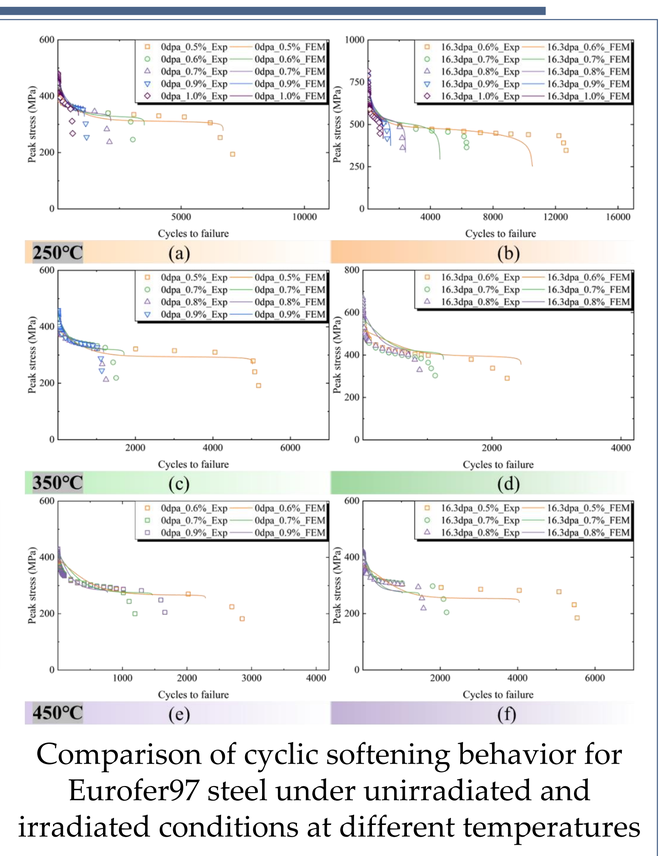
The relationship between the irradiation factor H, temperature T, and irradiation dose (dpa)



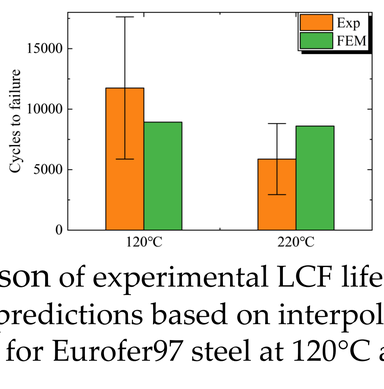
Modelling Strategy and Boundary Conditions for Finite Element Validation



Comparison of cyclic softening and hysteresis loops for Eurofer97 steel specimens at different temperatures



Comparison of cyclic softening behavior for Eurofer97 steel under unirradiated and irradiated conditions at different temperatures



Comparison of experimental LCF lifetime and FEM predictions based on interpolated parameters for Eurofer97 steel at 120°C and 220°C

Comparison of lifetimes without size effect

Comparison of lifetimes with size effect

Comparison of under size and irradiation effects

Conclusions

1. Accurately simulated Eurofer97's cyclic softening and hysteresis loops at various temperatures.

2. Effectively quantified and predicted the specimen size effect on LCF lifetime using a correction factor.

3. Reproduced the complex, temperature-dependent influence of neutron irradiation (up to 16.3 dpa) on mechanical behavior (hardening) and LCF lifetime, including low-temperature life extension and high-temperature degradation of irradiation effects.

4. Model-predicted LCF lifetimes showed good agreement with experimental data across diverse conditions, mostly within a 1.5-2.0 error band.