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Fracture Fatigue and Wear

A Unified Viscoplastic Damage Model for Predicting Low Cycle Fatigue Life of Eurofer97 under Coupled Temperature, Size and Neutron Irradiation Effects

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Introduction

Eurofer97 steel, a leading RAFM material for fusion reactors, experiences complex low-cycle fatigue under coupled temperature, irradiation, and size effects. This study develops a unified viscoplastic damage model by integrating an improved CDM approach with a modified Chaboche framework. The model enables accurate fatigue life prediction, supporting structural integrity assessment and fusion reactor component design.

Methods

A unified viscoplastic damage model is developed by coupling an improved CDM approach with the modified Chaboche constitutive framework.

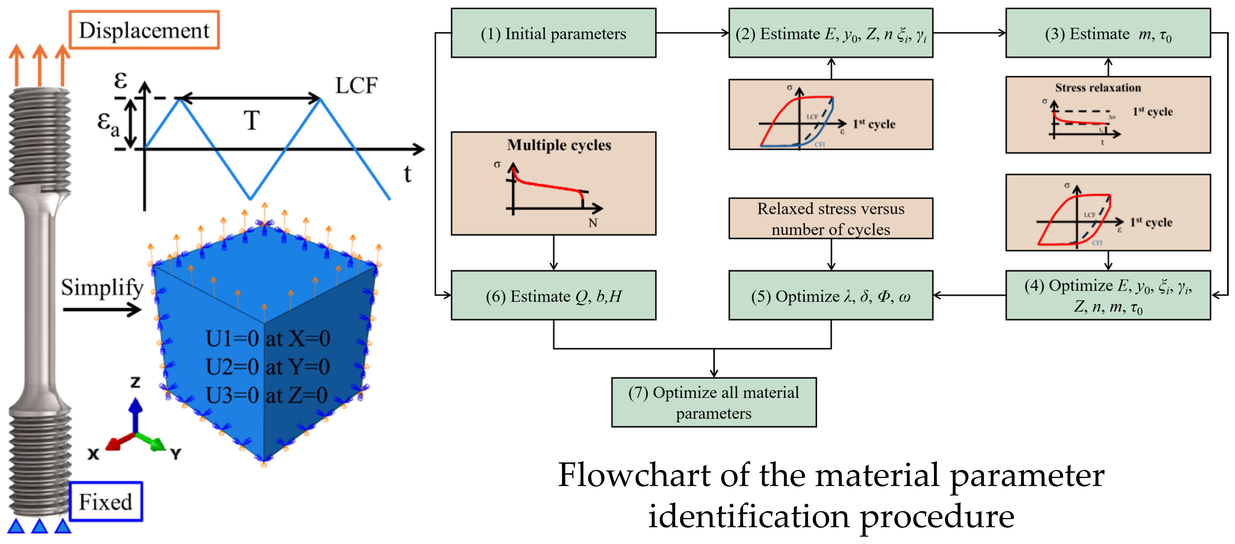
$$\Delta D = \left(\frac{\sigma_{eq}^{\ 2}}{2ES(1-D)^2} \right)^{s_0} \cdot \frac{\Delta p}{(1-D)^{\kappa}}$$

Irradiation hardening factor

$$IF(T, dpa) = \frac{\Delta\sigma_{irr}(T)}{\sigma_F(T)} + 1 = \frac{\sigma_s(T)}{\sigma_F(T)} \cdot \sqrt{1 - \exp\left(-\frac{dpa}{dpa_0(T)} \right)} + 1$$

Modification of Material parameters

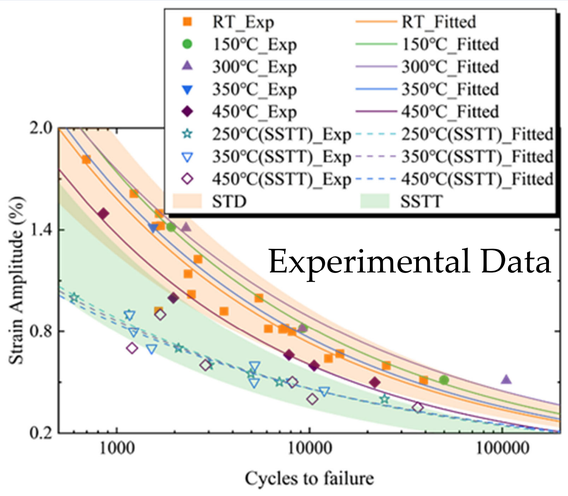
$$A^{irr} = A \cdot IF, \left(A = y_0, \gamma_1, \gamma_2, \xi_1, \xi_2, b, H, Q \right)$$



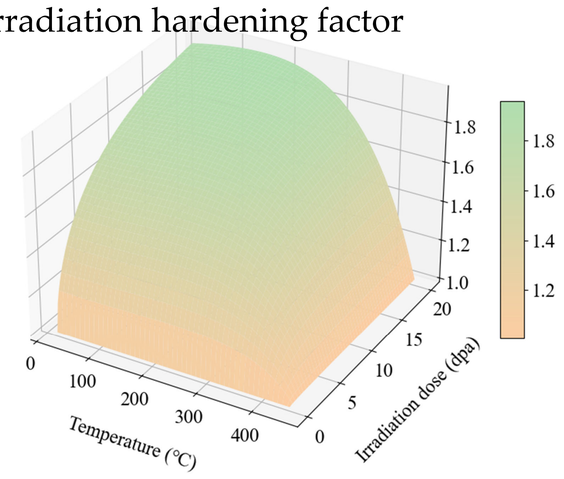
Modelling Strategy and Boundary Conditions

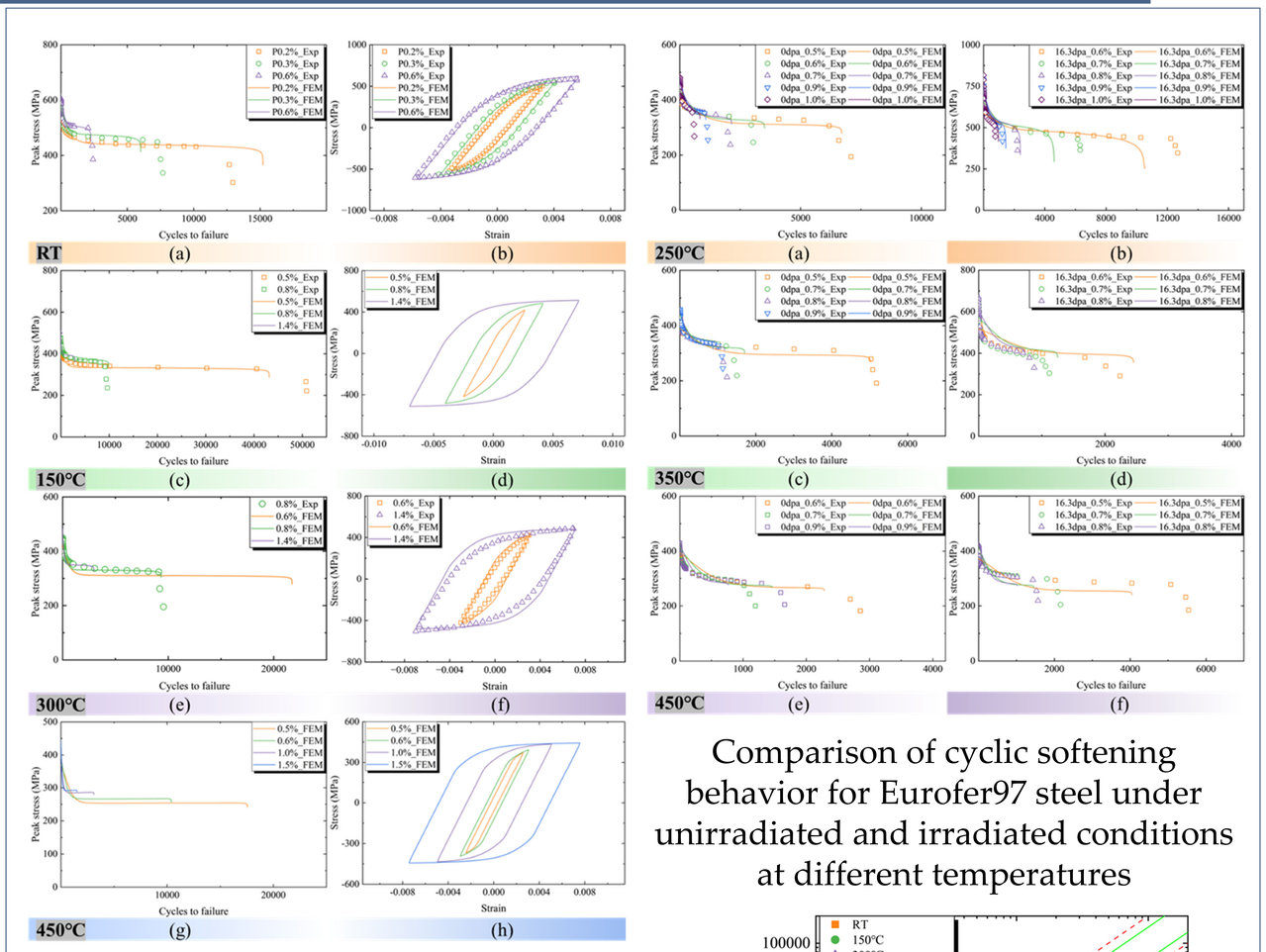
Flowchart of the material parameter identification procedure

Graphics / Images

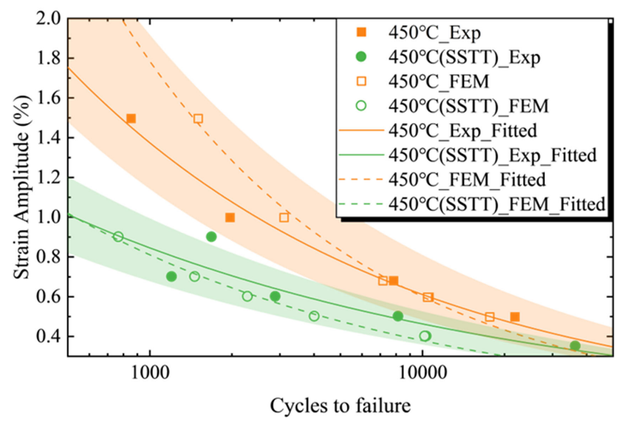


Irradiation hardening factor

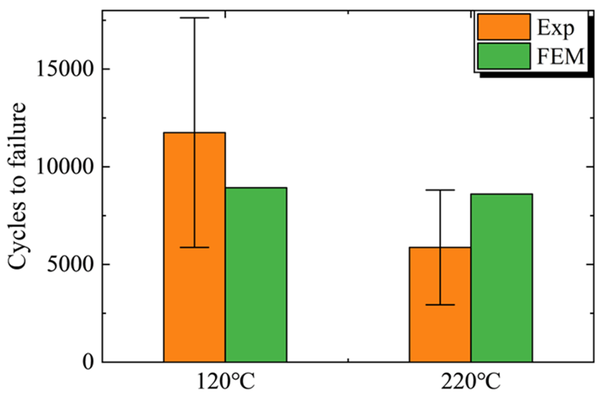




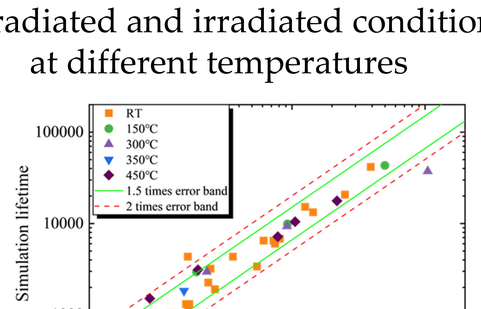
Comparison of cyclic softening and hysteresis loops for Eurofer97 steel specimens at different temperatures



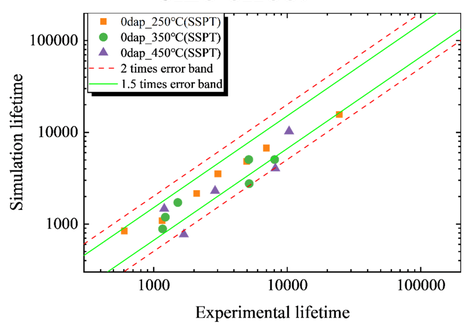
Comparison of LCF lifetime for Eurofer97 steel with and without size effect at 450°C



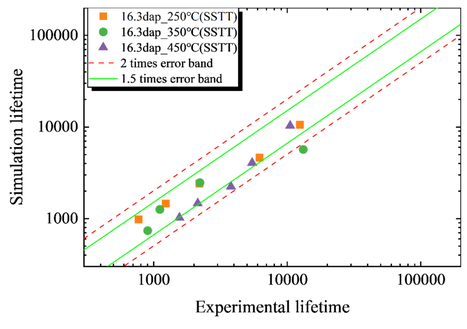
Comparison of experimental LCF lifetime and FEM predictions



Comparison of lifetimes without size effect



Comparison of lifetimes with size effect



Comparison of under size and irradiation effects

Conclusions

This study establishes a unified viscoplastic damage model for predicting the low-cycle fatigue behaviour of Eurofer97 under coupled temperature, specimen size, and neutron irradiation effects. The model shows good agreement with experimental results and captures irradiation-induced lifetime variations. It provides a reliable numerical tool for fatigue assessment and structural integrity evaluation of fusion reactor components.