Physics Informed Neural Network for Iterative Free Constitutive Integration of a Modified Chaboche Model for EUROFER97 at 250 °C

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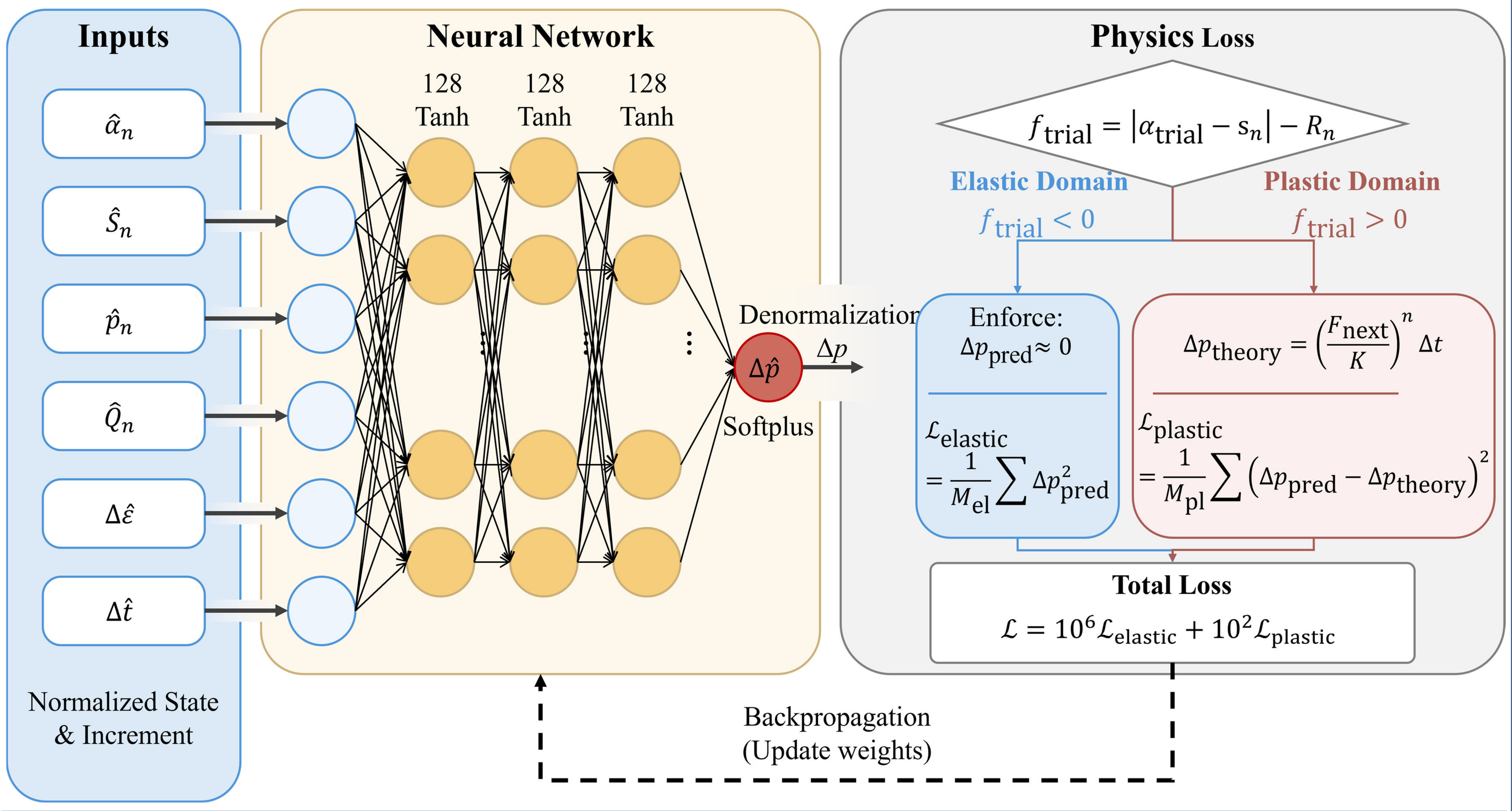
Introduction

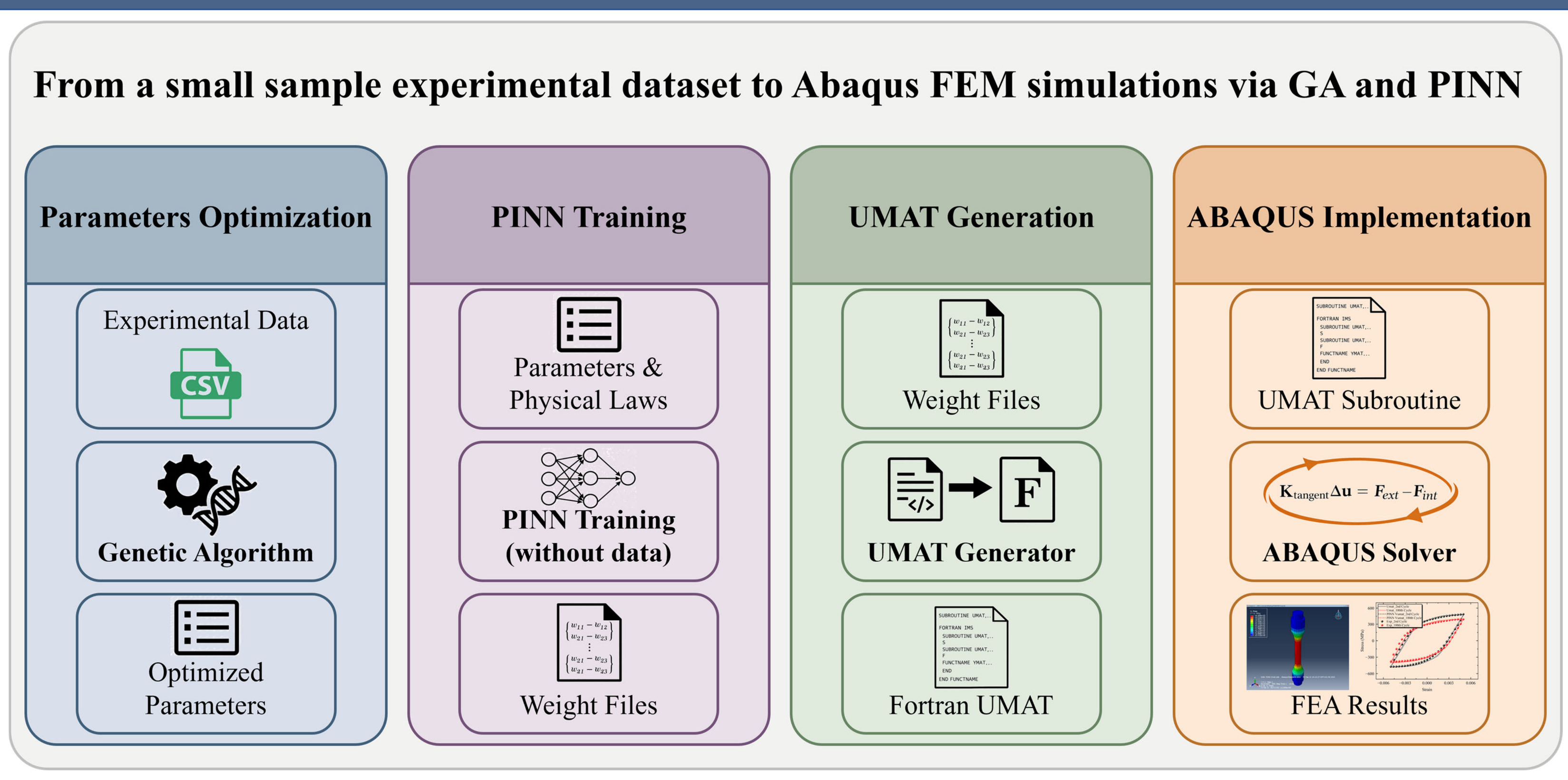
Accurate cyclic plasticity simulation of EUROFER97 steel is essential for assessing fusion reactor components, yet conventional Chaboche integration remains computationally expensive. This study develops a physics-informed neural network (PINN) surrogate to predict the inelastic increment directly, enabling iteration-free constitutive updates while preserving calibrated internal-variable evolution, cyclic hysteresis behavior, and Abaqus UMAT deployment efficiency.

Methods

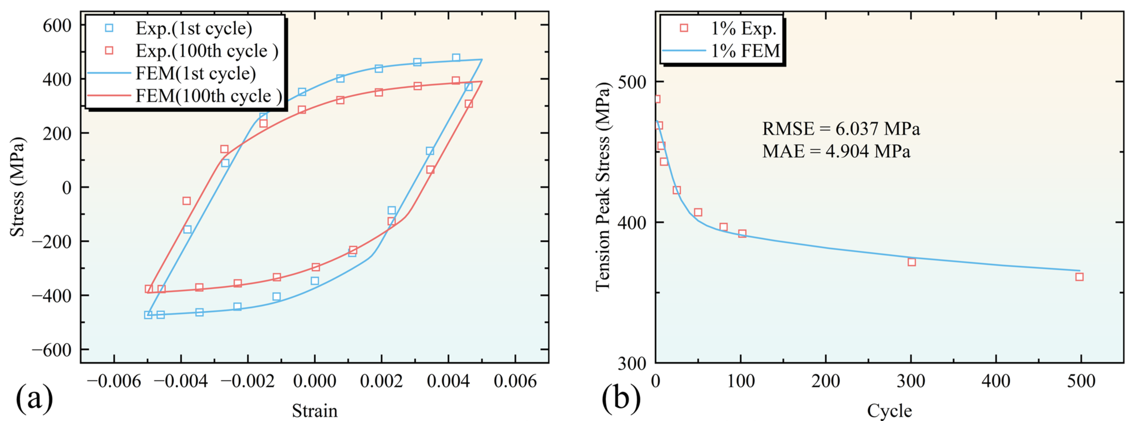
The research method focuses on developing a PINN-based constitutive integration model. The calibrated Chaboche equations are retained to update stress and internal variables, while the neural network predicts the inelastic increment Δp directly. This iteration-free surrogate is implemented in Abaqus UMAT to reproduce EUROFER97 cyclic plasticity and reduce simulation cost.



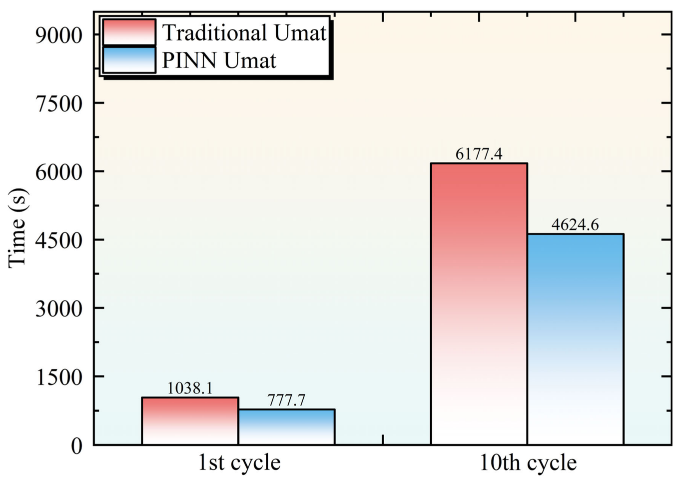
Graphics / Images



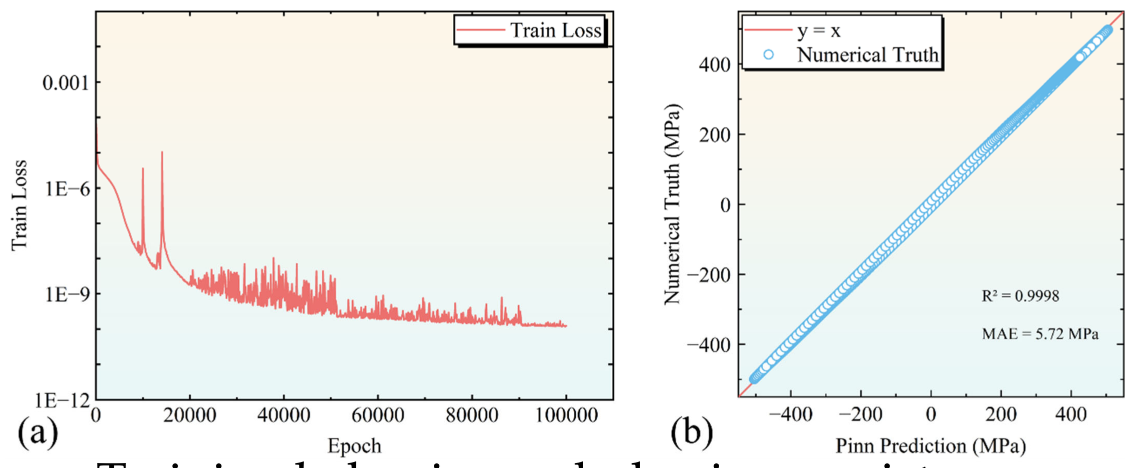
Overall workflow of the proposed framework for calibration, learning, and deployment, linking limited experimental data to Abaqus FE simulations



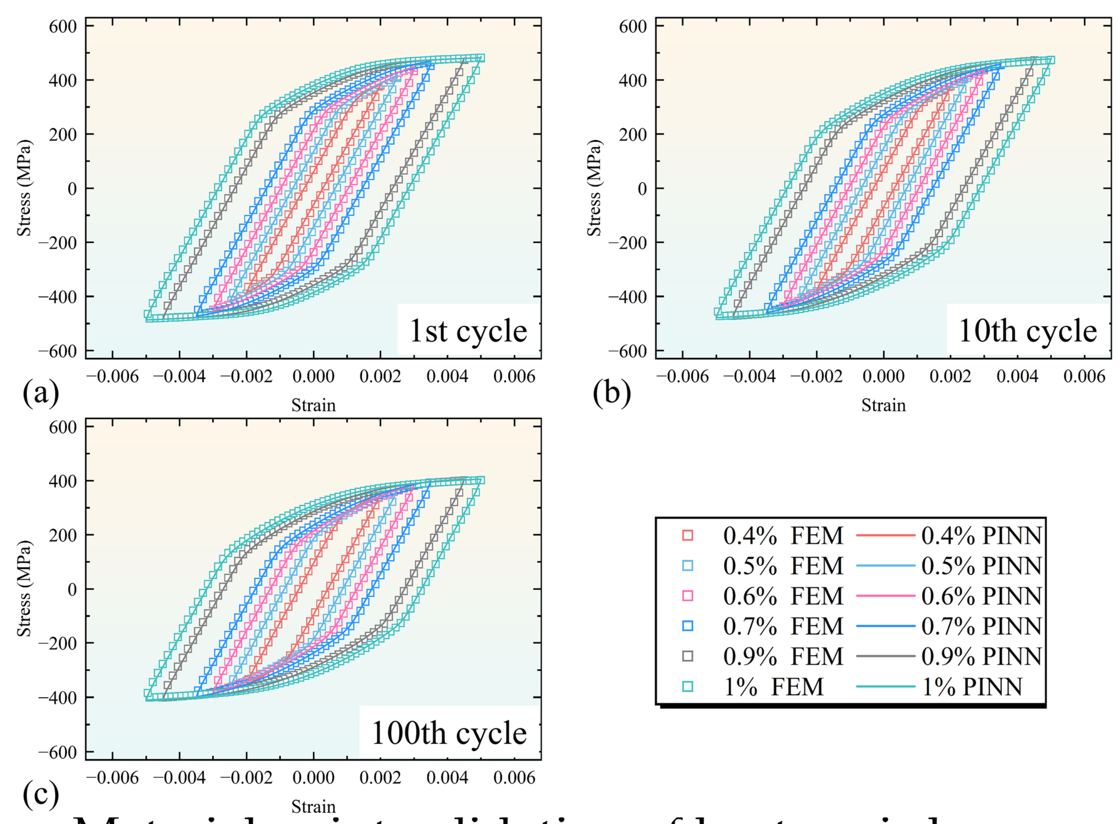
Accuracy of the GA calibrated



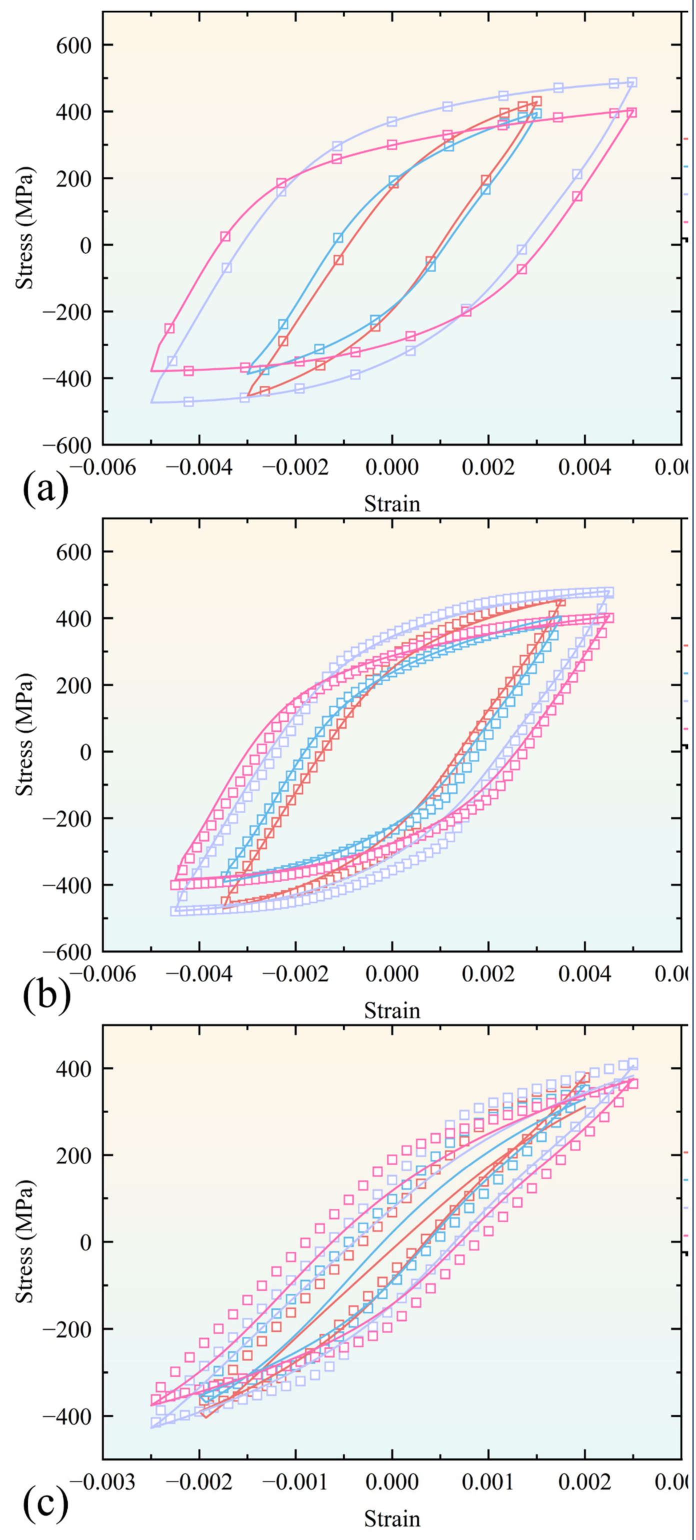
Computational efficiency comparison between the conventional UMAT and the PINN UMAT



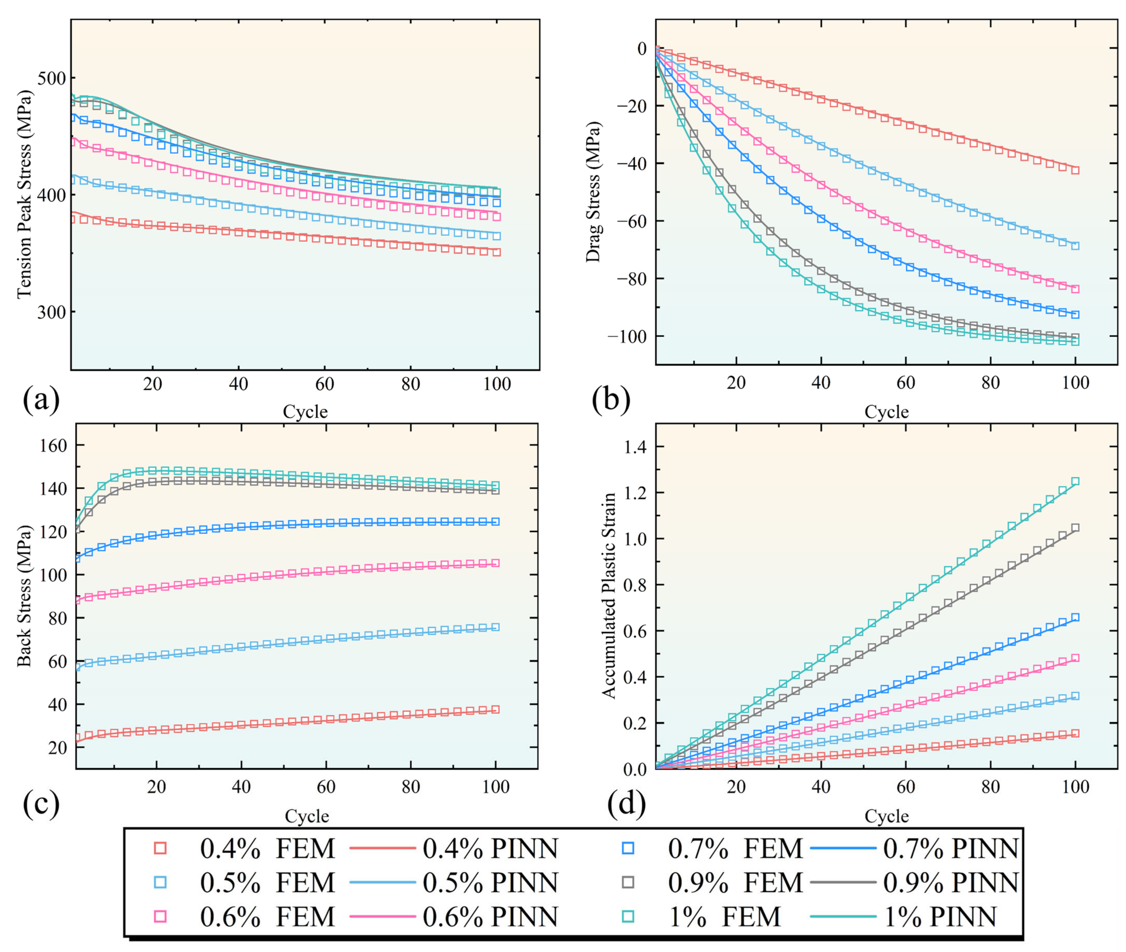
Training behavior and physics consistency



Material point validation of hysteresis loops



Comparison between the proposed PINN and a conventional conditional data-driven neural network



Cycle by cycle evolution of internal state variables

Conclusions

1. The GA calibrated modified Chaboche model provides a reliable physical baseline for the proposed surrogate framework.
2. The PINN accurately learns the local inelastic update while preserving cyclic response and internal variable evolution.
3. The PINN based UMAT achieves stable FE deployment with reduced computational cost.
4. Compared with the tested conditional stress-regression baseline, the proposed update surrogate better preserved loop closure and peak-stress evolution in the low-amplitude extrapolation cases.