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A Physics Guided Two Stage Neural Network Framework for Lifetime Prediction of Fretting Fatigue in Dovetail Joints

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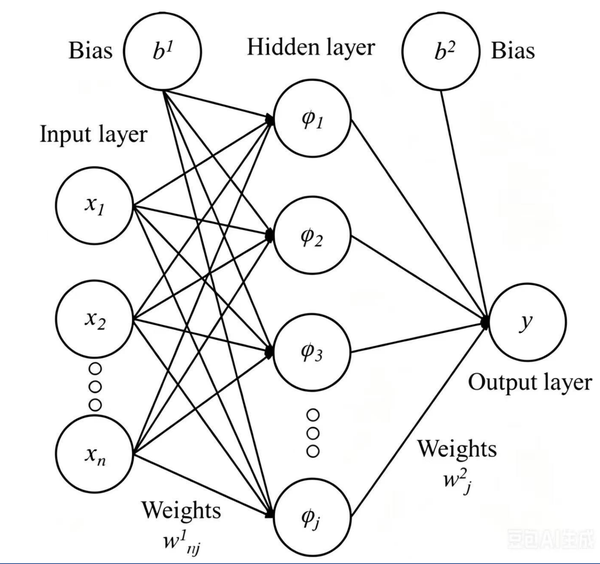
Introduction

A physically meaningful intermediate bridge variable, termed the contact surface parameter (CPS), is introduced to characterize the contact damage behaviour directly related to fretting fatigue crack initiation. First, finite element models of dovetail joints with different materials, structural configurations, and loading conditions are established to calculate CPS values. Subsequently, a first-stage neural network is trained to establish the mapping relationship between structural/loading parameters and CPS, thereby replacing repeated finite element analyses and improving computational efficiency. Then, a second-stage neural network is developed to correlate CPS with crack initiation life. Finally, experimental results are employed to validate the proposed framework.

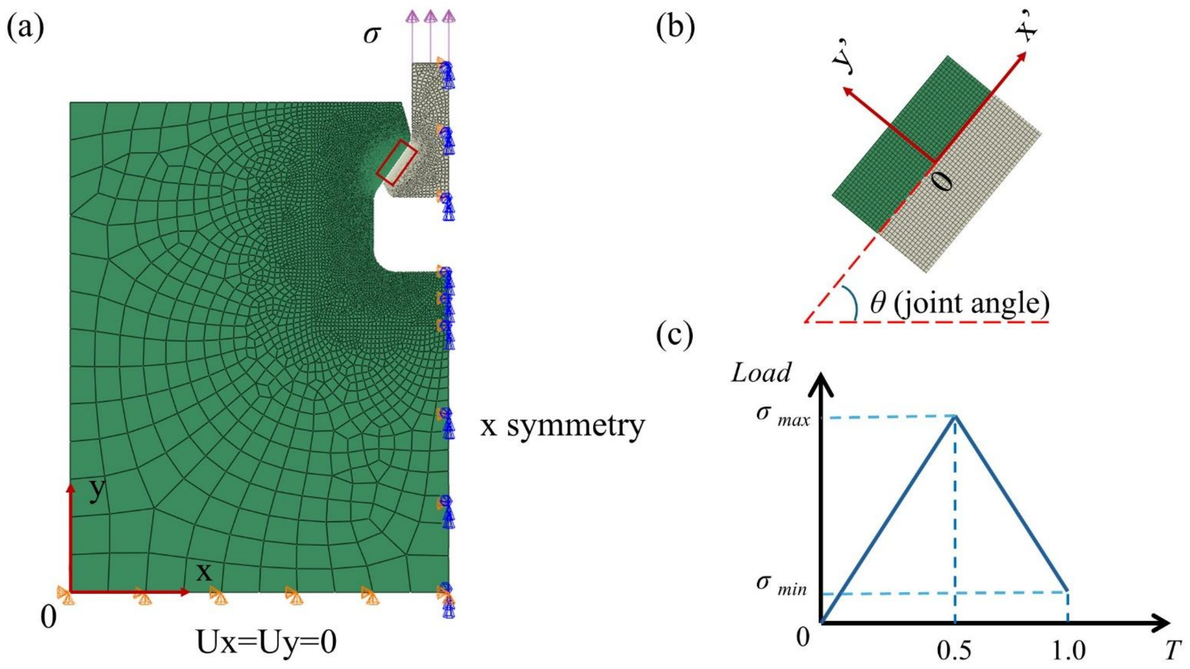
Methods

- Finite Element Method
- Critical Plane Approach
- Artificial Neural Networks

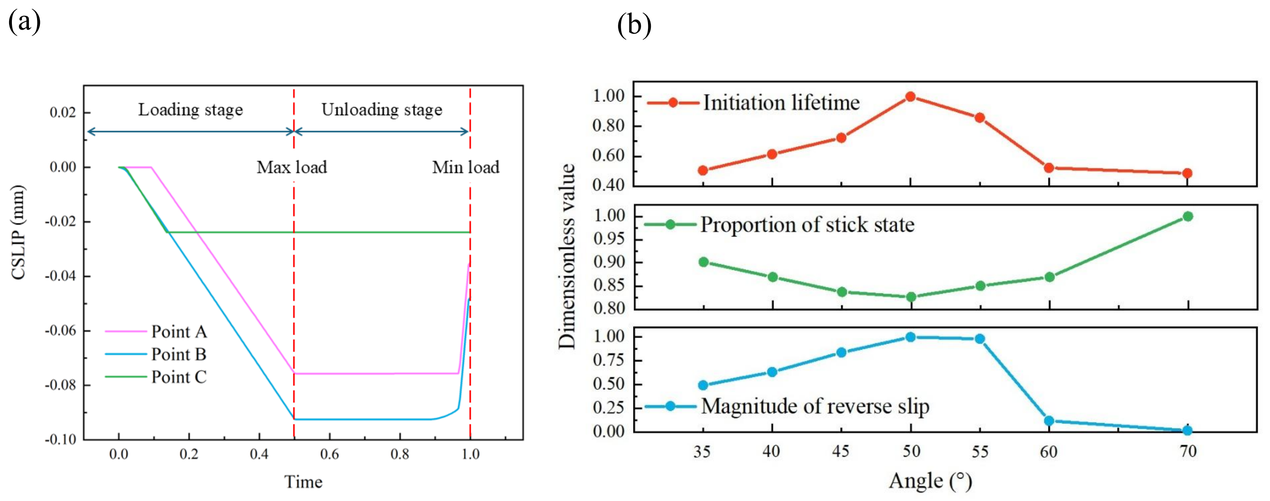
$$SWT = \sigma_{max}\frac{\Delta\varepsilon}{2} = \frac{\sigma_f'^2}{E}(2N_i)^b + \sigma_f'\varepsilon_f'(2N_i)^{b+c}$$



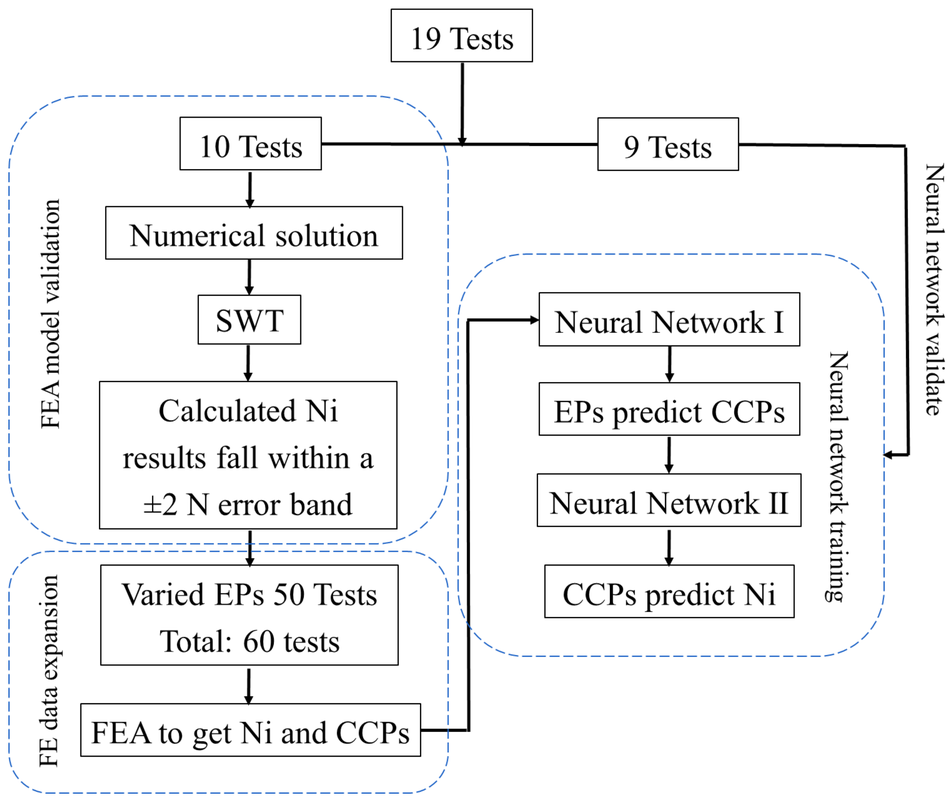
Graphics / Images



The FE model for the dovetail joint model:
(a) boundary and loading conditions, (b) enlarged view of the contact region, and (c) load application



Numerical and Experimental Results for T1-2
(a) 3D distribution of friction and (b) crack initiation positions in T1-2.



Flowchart demonstrating the procedure of predicting fretting fatigue lifetime

Conclusions

1.A mechanism-driven fretting fatigue crack initiation lifetime prediction framework was proposed based on the fundamental nature of fretting damage. By introducing the contact surface parameter (CPS), the model establishes a physically meaningful relationship between contact behavior and crack initiation lifetime.

2.The proposed method enables rapid evaluation of crack initiation lifetime using EPs/CPS, significantly reducing the dependence on repeated finite element simulations and improving computational efficiency for engineering applications.

3.A two-stage neural network architecture was developed to avoid a purely black-box prediction model and enhance physical interpretability. Moreover, a unified prediction framework was established for the first time to predict fretting fatigue lifetime of dovetail joints under different materials, structural configurations, and deformation/loading conditions.