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Physics-informed neural networks for estimating stress transfer mechanics in single lap joints

Key words: Physics-informed neural networks (PINNs); Algorithmic differentiation; Artificial neural networks; Loss function; Single lap joint

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Motivation

- Physics-informed neural networks (PINNs) are neural networks trained to solve supervised learning tasks while satisfying the applicable laws of physics described by general nonlinear PDEs.
- PINNs can replace the traditional discretization methods with a neural network that approximates the solutions of differential equations.
- In this study, the interfacial and normal stresses in a lap joint are estimated using PINNs.
- **Novelties:** (i) The creation of a novel PINN-based DML approach to solve two non-homogeneous coupled fourth-order PDEs. (ii) Validation of the results obtained via the developed methodology and the results obtained via closed form solutions (MAPLE software).
- **Methodology:** An ANN consisting of an input layer, hidden layers, and an output layer is developed. The boundary and initial conditions along with the material properties of the constituents of a lap joint were supplied to the input layer, the loss function is calculated in the hidden layers and the final values of the stresses $\sigma 1$ and $\sigma 3$ satisfying the boundary conditions are extracted from the output layer.

Methodology

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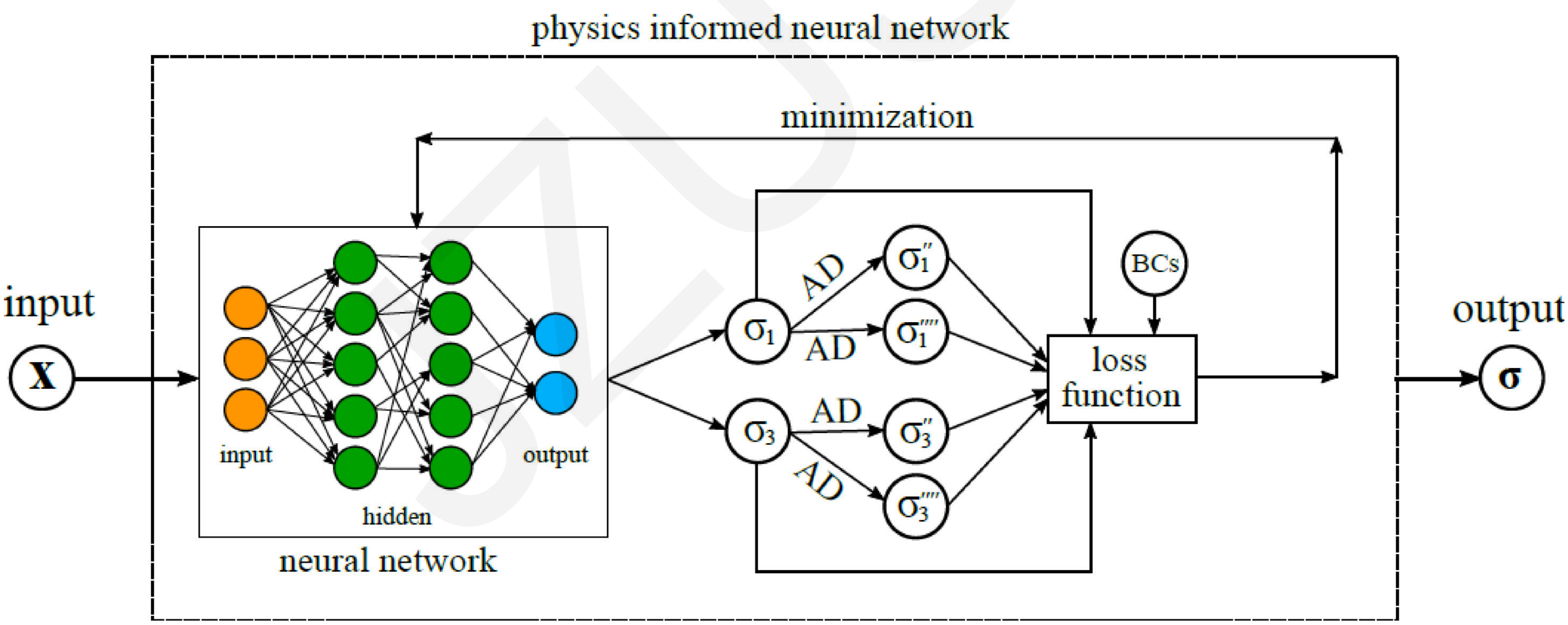
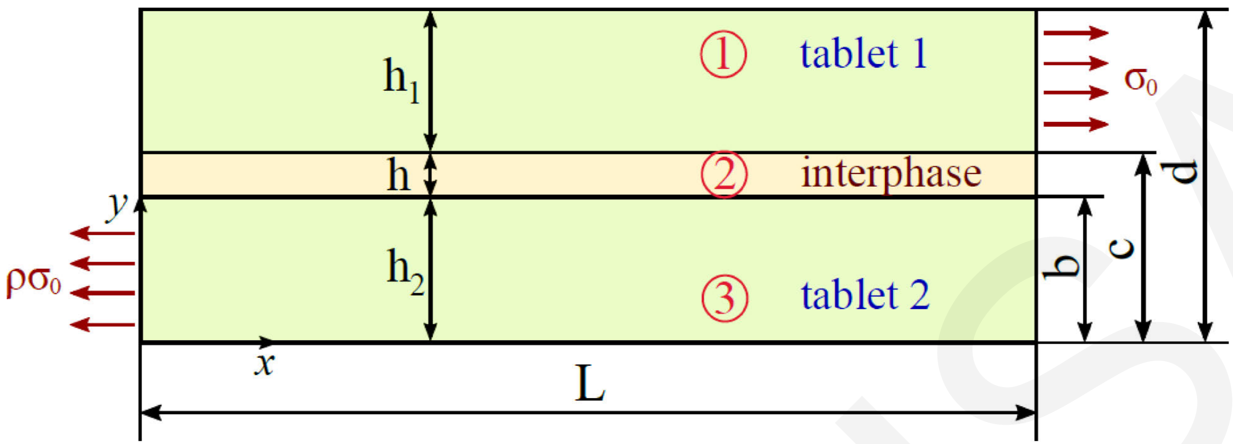
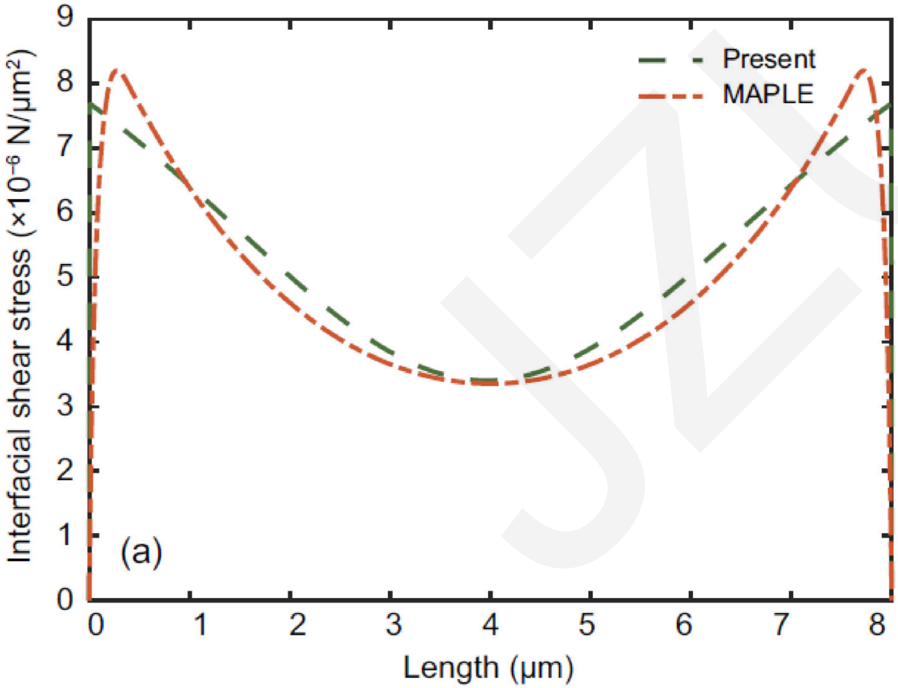


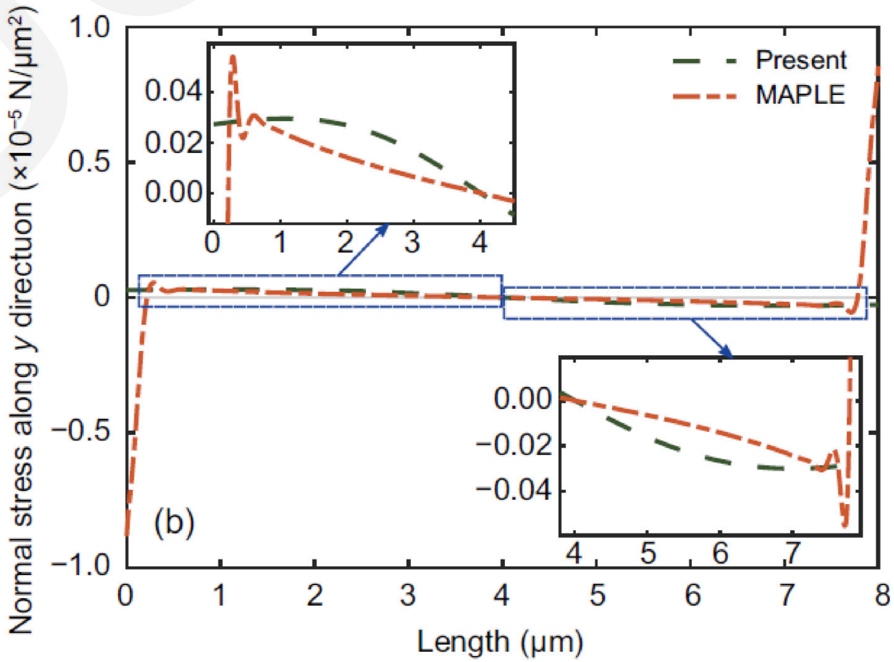
Results



①
tablet 1
②
interphase
③
tablet 2
h1
h
h2
y
x
L
b
c
d
σ0
ρσ0



Interfacial shear stress (×10⁻⁶ N/μm²)
Length (μm)
Present
MAPLE
(a)



Normal stress along y directuon (×10⁻⁵ N/μm²)
Length (μm)
Present
MAPLE
(b)

Conclusions

- The mechanics of a single lap joint were investigated by solving a DML-based PINN. A uniaxial loading parallel to the tablet length was applied on the right edge of the upper tablet while keeping the lower tablet fixed.
- The developed framework was then extended to estimate the various stress components by solving the coupled fourth-order non-homogeneous PDEs equations subjected to the boundary conditions.
- The interfacial shear stress estimated using the proposed DML based approach is found to represent the physical behavior, although the physical behavior at the interphase edges is unable to be captured.
- The method of using deep learning to solve the differential equations is a promising approach - the developed deep learning methodology can be used to solve complex equations in real time.