Graph neural network modeling of time-dependent materials under indentation

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Abstract

Indentation offers advantages over other tests, being non-destructive, requiring minimal material, and adaptable to multi-layered
samples like polymer-coated steel plates. However, calibrating constitutive models by iteratively matching experimental indentation
force-displacement curves via FEM simulations is computationally intensive. This study addresses the indentation curve matching
problem by using a Graph Neural Network (GNN)-based surrogate model to reduce calibration time for viscoelastic materials.
By combining GNN with Gated Recurrent Units (GRUs) to capture the material temporal dependency, the model can infer stress-
displacement fields as well as the corresponding force-displacement curves using both synthetic and experimental data for training.
Performing calibration through an indentation test on a polymer-coated steel panel, the model demonstrates a significant reduction in
computational time compared to traditional FEM methods while accurately inferring stress and displacement fields. The surrogate
model reliably predicts material behavior within the training range of the parameters, making the trained GNN well-suited for
materials that can be described by the same constitutive model used to generate the synthetic data. This study, by improving existing
GNN architectures, develops the first surrogate model of a 2D FEM model that includes viscoelasticity and contact. Additionally, a
novel procedure for calibrating viscoelastic materials through indentation testing is presented, suitable for samples like thin polymer
layer coatings on steel panels. The generality of this procedure highlights its potential applicability to manufacturing processes,
such as optimizing the indenting pattern applied to soft coatings on metal sheet in a roll-to-roll hot embossing process.

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