18th European Mechanics of Materials Conference (EMMC18)
April 4 - 6, 2022, Oxford, UK

Multiscale modeling of inelastic microstructured materials with Thermodynamics-based Artificial Neural Networks (TANN)

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The mechanical behavior of inelastic materials with microstructure is very complex and hard to grasp with heuristic, empirical constitutive models. For this purpose, multiscale and homogenization approaches are often used for performing reliable, accurate predictions of the macroscopic mechanical behavior of microstructured solids. Yet, the calculation cost of such approaches is extremely high and prohibitive for real-scale applications involving inelastic materials.
Recently, data-driven approaches based on deep learning have risen as promising alternatives to replace ad-hoc constitutive laws and speed-up multiscale numerical methods. However, they lack often a rigorous frame based on the laws of physics and their application to materials with complex microstructure is not yet established.

Here, we propose Thermodynamics-based Artificial Neural Networks (TANN) for the constitutive modeling of materials with inelastic and complex microstructure [1]. Our approach integrates thermodynamics-aware dimensionality reduction techniques and deep neural networks to identify the constitutive laws and the internal state variables of complex inelastic materials [2].
The ability of TANN in delivering high-fidelity, physically consistent predictions is demonstrated through several examples both at the microscopic and macroscopic scale. In particular, we show the efficiency and accuracy of TANN in predicting the average and local stress-strain response, the internal energy and the dissipation of both regular and perturbed lattice microstructures in inelasticity. Finally, a double-scale homogenization scheme is used to solve a large scale boundary value problem. The high performance of the homogenized model using TANN is illustrated through detailed comparisons. An excellent agreement is shown for a variety of monotonous and cyclic stress-strain paths, with a calculation cost reduced by several orders of magnitude.

REFERENCES

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