Physics-Informed Extreme Learning Machine for the Analysis of Laminated Composite Nanoshells

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Composite nanoshells are largely employed as load-carrying elements in advanced micro- and nano-scale systems for their excellent mechanical properties. However, their microstructural behavior remains still not completely understood, largely due to the lack of general and efficient analysis tools. Analytical solutions are limited to simple configurations, while numerical methods based on finite elements are often computationally expensive.

This work presents a novel computational tool that can accurately capture the microscale effects of laminated nanoshells under arbitrary stacking sequences, boundary conditions, and geometries, with improved computational performance. The shell mathematical model is formulated within a Kirchhoff–Love strain-gradient shell theory derived using the differential geometry of surfaces. For the numerical solution, we employ a mesh-free method which combines Physics-Informed Neural Networks (PINNs) and Extreme Learning Machines (ELMs). The proposed Physics-Informed Extreme Learning Machine (PIELM) framework enables efficient solution of the higher-order partial differential equations inherent of nonlocal shell theories, alleviating the computational cost associated with mixed or higher-continuity finite element formulations.

The efficiency of this tool is exploited to investigate microscale effects across different nanoshell configurations, providing new insights into their mechanical behavior. Overall, the proposed framework offers a versatile tool to support the analysis and design of composite nanoshells in micro- and nano-structures.

Acknowledgements:
The publication was made with funding from the Ministry of University and Research (MUR) under the FIS2 Grant, Project TOSSTO no. FIS-2023-01465, (CUP: J53C25000610001).