

Isotropic metamaterial stiffness beyond Hashin-Shtrikman upper bound and Numerical investigation of thin plates and shallow shells with point defects and metric anomalies

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ABSTRACT

My research presentation at IISC Bengaluru includes two topics covering my Postdoc and PhD research work. My postdoctoral research aims to create isotropic mechanical metamaterials using anisotropic structures (plate lattices) made with anisotropic materials. Sustainable development necessitates minimizing material usage while maintaining the required load-bearing capacity across industries such as transportation, structural engineering, and prosthetics. This objective can be achieved using lattice structures with a high stiffness-to-density ratio. However, conventional lattices are inherently anisotropic, making them unsuitable for multi-directional load-bearing applications due to their direction-dependent stiffness. This limitation underscores the need to design isotropic lattices with enhanced specific stiffness. In my recent work, I have shown that the material and structural anisotropies can mutually reinforce each other to realize the overall isotropic response, without incurring the mass penalty, thus surpassing the Hashin-Shtrikman (H-S) upper bound. For the past 62 years, the H-S upper bound has been considered the theoretical limit for the elastic stiffness of general isotropic composites and porous materials. Researchers have long sought to reach this limit to advance the performance of structural materials used in automotive, aerospace, construction and medical industries. This discovery marks a breakthrough in the field and redefined the previously accepted theoretical limit. While these structures pose challenges for 3D printing due to their closed-cell nature, recent progress in this area has opened up exciting possibilities for their application in industries.

My PhD thesis incorporates the numerical investigations of the deformed shape and stress distribution of materially uniform elastic Foppl-von Karman surfaces. Thin structures like thin plates and shallow shells, are influenced by intriguing factors like point defects (disclination, dislocation) and metric anomalies (growth, thermal strain). Solving the Foppl-von Karman equations which are nonlinear partial differential equations analytically is challenging. I have developed nonlinear finite element code in MATLAB to solve various boundary value problems for bounded Foppl-von Karman elastic plates and shallow shells. The results have been eye-opening, revealing the impact of singular point defects, boundary conditions (free, simply supported, partially clamped), and intriguing bifurcation phenomena in these structures. Additionally, I have addressed the complexities of growth strains, exploring how coexisting defects and thermal/growth strains can either enhance or counteract each other's influence on the mechanics of the surface. To validate my numerical findings, I have conducted hands-on experiments using paper models to showcase point defects and their deformation phenomena.

ABOUT THE SPEAKER

I am currently a Research Fellow in Mechanical and Aerospace Engineering at Nanyang Technological University, Singapore. I specialize in continuum mechanics, nonlinear finite element methods, and machine-learning-assisted simulation of structural mechanics problem. I completed my PhD in Mechanical Engineering from IIT Kanpur, where my work focused on numerical modeling of thin plates and shells with defects and metric anomalies. During my doctoral and postdoctoral work, I have broadened my portfolio to include the mechanics of architected and programmable materials, computational mechanics, and data-driven approaches such as physics-informed neural networks for solving nonlinear problems in solid mechanics. I have published in leading journals such as Physical Review E, Proceedings of the Royal Society A, Soft Matter, Journal of Applied Mechanics and Journal of the Mechanics and Physics of the Solids.

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