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Shape Sensing of Sandwich Beams using the inverse FEM: Formulation, Numerical and Experimental Assessment

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ABSTRACT

Shape sensing is the inverse problem of reconstructing the displacement field of a structure from discrete strain measurements. From displacements, full-field strains and stresses can also be evaluated, enabling Structural Health Monitoring, the control of morphed structures, and the development of predictive maintenance strategies and Digital Twin technologies.

Among the various approaches proposed for shape sensing, the inverse Finite Element Method (iFEM) has emerged as particularly effective due to its versatility regarding complex loading conditions, material systems, and geometries. Based on the FEM discretization of the analyzed component and on the least-square compatibility between measured and reconstructed strains, iFEM has been initially formulated for thin-walled components, then extended to beam and frame structures and more recently to moderately thick multilayered plates.

This paper develops a one-dimensional inverse element for the shape sensing of multilayered composite and sandwich beams. The formulation couples the iFEM technique and the Refined Zigzag Theory for multilayered structures. The performance of the proposed element is assessed through both numerical analyses and experimental tests on sandwich beams subjected to bending. Strains evaluated/measured on the external surfaces and at one of the facesheet-core interfaces serve as input data for the 1D inverse approach, while reference deflections evaluated/measured at key locations are used to numerically/experimentally validate the accuracy of the reconstruction. The paper focuses on different approaches to deal with the compatibility between reconstructed and measured strains. In particular, an investigation on the importance of including transverse shear strain contributions is performed for different sandwich stacking sequences.

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