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Advanced isogeometric methods with a focus on composite laminated structures

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Abstract

The design and optimization of engineering products demand faster development and better results at lower costs. These challenging objectives can be achieved by readily evaluating multiple design options at the very early stages of the engineering design process. To this end, accurate and cost-efficient computational modeling techniques for solids and fluids offer a reliable support and enable a better understanding of the underlying complex physical phenomena. The present study focuses on the development of advanced computational tools in the context of Isogeometric Analysis (IgA) [1], trying to exploit its higher-order continuity properties and typically excellent accuracy-to-computational-effort ratio.

Here, we first focus on an accurate and cost-efficient computational strategy to model laminated structures comprising solid plates, bivariate Kirchhoff's plates, and solid shells. In brief, we first calculate an efficient and accurate approximation of the displacement field (and its derivatives) using a single-element through the thickness of the laminate in combination with either a layer-by-layer integration rule or a homogenized approach. This relatively inexpensive calculation renders an excellent approximation of the laminate in-plane stresses only. Instead, to recover the out-of-plane stress components, we propose a pointwise post-processing technique that is based on the direct integration of the equilibrium equations in strong form, involving the straightforward computation of high-order derivatives of the displacement field, which can be computed relying on the properties of IgA shape functions.

Then, we further develop a novel solution technique for phase-field modeling of crack propagation using IgA. One of the key features of a crack evolution process is that a fracture cannot heal and, therefore, it is a non-reversible process. Thus, we propose a novel approach for a rigorous enforcement of the irreversibility constraint, which grants non-negative damage increments under prescribed displacements and may be efficiently resolved further providing a reduction of the computational time with respect to state-of-the-art methods to solve phase-field brittle fracture.

Finally, we explore new IgA collocation (IgC) formulations in the context of fluid-structure interaction (FSI). Computational fluid dynamics problems are a paradigmatic example in which IgC can provide the superior geometric capabilities of IgA with a lower computational cost and comparable accuracy with respect to standard IgA Galerkin discretizations. Thus, to obtain a geometrically compatible coupling fluid-structure interface for FSI problems, we propose to adopt a common spline description of the interface, combining IgC on the structural side and boundary-conforming finite elements (like the so-called NURBS- enhanced finite elements) on the fluid side.

References

[1] T.J.R. HUGHES, J.A. COTTRELL, Y. BAZILEVS, *Isogeometric analysis: CAD, finite elements, NURBS, exact geometry and mesh refinement*, Computer Methods in Applied Mechanics and Engineering, Elsevier (2005), 194 (39-41), pp. 4135-4195