Virtual Testing of Composite Pressure Vessels Using Isogeometric Analysis

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ABSTRACT

Composite pressure vessels exhibit complex structural behavior due to strongly inhomogeneous and anisotropic mechanical properties resulting from the material architecture and the manufacturing process. Design codes for composite pressure vessels require extensive prototype testing. There exists a high desire to simulate these expensive tests by virtual tests for use in a design-by-analysis approach [1]. Today, finite element analysis is the only method with sufficient generality for a thorough analysis of composite pressure vessels. The finite element analysis of composite pressure vessels is based on preliminary design for shape optimization of the vessel contour and on filament winding simulation for the determination of key geometric data of the composite shell. The data is continuous and typically comprises the isotensoid contour, the fiber angle and thickness distributions of the individual layers and the resulting wall thickness distribution [2]. Usually this data is represented using piecewise linear functions as is common in commercial filament winding simulation software. However, this smooth data can be naturally described using spline functions. Isogeometric analysis is unique in the sense that geometric data can be represented exactly in the analysis. Moreover, the refinement strategies available in isogeometric analysis are promising for the efficient resolution of multi-layered structures with typically up to hundred layers as they are found in thick-walled composite pressure vessels. This motivates the investigation of isogeometric analysis technology as a basis for virtual testing of composite pressure vessels. An isogeometric analysis model for composite pressure vessels based on an improved filament winding simulation is developed. To this end, an existing object-oriented finite element code is enhanced to support the isogeometric analysis technology. Results are compared with solutions obtained by standard finite element analysis using layered solid elements [3]. The importance of the physical interpretation of the element integration scheme for isogeometric analysis is realized. The results motivate the investigation of a fiber-bundle approach [4] as an alternative to the layer-based approach as an avenue for further research. Applications are in the safe and efficient design of composite pressure vessels for mobile applications, e.g., high-pressure hydrogen tanks in alternative automotive propulsion systems.

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