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Isogeometric Kirchhoff-Love shell formulation for elasto-plasticity

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Abstract

An isogeometric thin shell formulation allowing for large-strain plastic deformation is presented. A stress-based approach is adopted, which means that the constitutive equations are evaluated at different integration points through the thickness, allowing the use of general 3D material models. The plane stress constraint is satisfied by iteratively updating the thickness stretch at the integration points. The deformation of the shell structure is completely described by the deformation of its midsurface, and, furthermore, the formulation is rotation-free, which means that the discrete shell model involves only three degrees of freedom. Several numerical benchmark examples, with comparison to fully 3D solid simulations, confirm the accuracy and efficiency of the proposed formulation.

Keywords: Isogeometric; Kirchhoff-Love; Thin shell; Finite strain; Elastoplastic

1 Introduction

Shell structures play a central role in engineering design within many different disciplines, e.g., mechanical, aerospace, marine, and civil engineering, due to their high ratio of load capacity to self weight. In many cases, structural analysis of such structures needs to extend from the elastic to the plastic regime, e.g., when assessing the ultimate load capacity of the structure or when plastic deformations are part of the manufacturing process, like in sheet metal forming. The analysis of such highly nonlinear processes is widely done with nonlinear finite element (FE) analysis, and shell elements are typically employed for reducing the computational effort.

Formulating shell elements that account for large-strain plastic deformations is very challenging and a lot of research has been dedicated to such developments. From the modeling perspective, the crucial issue concerns the formulation and implementation of inelastic constitutive models. Two different classical approaches can be adopted: (i) to use *stress resultant* plasticity where the elastoplastic constitutive models are formulated entirely based on stress resultants, see e.g. [1] - [6], or (ii) to define integration points in the thickness direction of the shell and to use *stress-based* three dimensional (3D) plasticity models. The stress resultants are obtained by integration through the thickness of the shell, see e.g. [7] - [11]. With the *stress resultant* formulation, the derivation of inelastic stress resultant constitutive models is very difficult from the solid constitutive models. Even the simplest von-Mises yield function leads to a rather complex functional form when expressed in stress resultants and also the