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D.T. Filipovic, G.R. Kress

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A planar finite element formulation for corrugated laminates under transverse shear loading

D.T. Filipovic[a,*], G.R. Kress[a,]

[a] *Laboratory of Composite Materials and Adaptive Structures, Department of Mechanical and Process Engineering, ETH Zürich, Tannenstr. 3, CH-8092 Zürich, Switzerland*

Abstract

This paper contributes a planar finite-element unit-cell formulation based on the principle of virtual displacements for simulating the structural as well as the local transverse-shear response of thick-walled corrugated laminates. The theory observes that bending-strain gradients are invariable under constant internal force held in equilibrium by the transverse shear stresses in the corrugated cross-section. It is explained how the load information is transmitted by macro strains which are valid for arbitrary laminates. The unit-cell model assumes periodicity of the corrugation pattern and homogeneity of the global load. Postprocessing aspects include best-fit of the warped cross-section to a vertical plane and extrapolation of the secondary solutions with quadratic polynomials fitted to results at the Barlow points of a Lagrange type finite element with cubic shape functions. Simulation results with the proprietary software show peculiar stress redistributions and it is explained how these are caused by an interplay of geometry, equilibrium, and homogeneous natural boundary conditions. A convergence study along with model verification is included.

Keywords: planar finite element formulation, composite materials, corrugated laminates, out-of-plane shear

1. Introduction

Corrugated laminates with high corrugation amplitude can reach extreme anisotropy with high bending stiffness about the direction of the corrugations and low bending stiffness about the non-corrugated direction. The placement of most material particles away from the mid-plane in the cross-section seen in Fig. 1 provides

Figure 1: High-amplitude corrugated laminate with reference coordinate convention

high bending stiffness combined with relatively low transverse shear stiffness. Because of its open geometry, the corrugated laminate provides less transverse shear stiffness than a sandwich design with its closed face sheets.

1.1. Motivation

Because of the extreme anisotropy rectangular high-amplitude corrugated plates carry transverse load almost unilaterally, like a beam, and at moderate span lengths the deflection is significantly increased by transverse shear compliance [1]. Because of the geometric complexity of corrugated laminates, numerically efficient simulation tools are needed to provide transverse shear stiffness values for homogenized substitute-plate models. Beyond the needs of large-scale structural analysis, transverse shear force may create interesting effects in moderately thick laminates, i.e. where the laminate thickness is not so much smaller than the corrugation amplitude or periodic length. The effects include local interlaminar shear stress in the laminate which may pose limits to structural strength.

*Corresponding author

Email address: fidaniel@ethz.ch (D.T. Filipovic)