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Explicit Tangent Stiffness Matrix for the Geometrically Nonlinear Analysis of Laminated Composite Frame Structures

Ardalan R. Sofi[1], Peter L. Bishay[2*], Satya N. Atluri[3]

Abstract

In this paper, based on Von Kármán's nonlinear theory and the classical lamination theory, a closed form expression is derived for the tangent stiffness matrix of a laminated composite beam element undergoing large deformation and rotation under mechanical and hygrothermal loads. Stretching, bending and torsion have been considered. A co-rotational element reference frame is used as the Updated Lagrangian (UL) formulation. The model has been verified in different problems by comparison with the results of Nastran and ANSYS composite laminate tools, and the difference in the resulting large deformations is less than 5%. The major advantage of the proposed approach is that the composite structure is modeled using 1D beam elements rather than 2D shell or 3D solid elements as in the case of Nastran and ANSYS where laminates are defined over surface or 3D solids. The availability of an explicit expression for the tangent stiffness matrix makes the proposed model highly efficient specially when dealing with large composite space frame structures. The saving in computational time could reach 93% compared to regular FE software packages. The developed model is very useful for modeling and designing flexible composites used in new applications such as morphing aerospace structures and flexible robots.

Keywords: Large deformation; Updated Lagrangian; Finite elements; Composite beams.

1 Introduction

With the appearance of new technologies and inventions in the fields of automotive design, aerospace structures, smart structures, and robotics, the design and manufacturing of laminated composite materials have seen a lot of development. Beside the well-known applications of fiber-reinforced laminated composite materials because of their various advantages, such as high specific stiffness and strength, high corrosion resistance, good thermal insulation, fatigue resistance and damping properties, new applications of composite materials emerged that necessitates new effective and efficient tools and approaches in design and simulation. For example, a lot of smart material elements, such as shape memory alloy (SMA) wires or ribbons and piezoelectric patches or fibers, are embedded in polymer composite laminates to form smart composite structures with multi-functions such as sensing, actuating and load bearing [1]-[3]. Another example is the design of morphing aerospace structures, such as morphing wings with flexible seamless control surfaces or flexible winglets [4]. The design of such structures is challenging because of the need to have flexible, yet strong, wing skins that can morph to different shapes and still be able to stand aerodynamic loads. Composite actuators combining shape memory wires, glass fibers in a soft matrix that could morph into complex shapes

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