DESIGN CONCEPTS FOR LAMINATED COMPOSITE MATERIALS WITH THERMAL AND/OR MECHANICAL COUPLING RESPONSE.[*]

CHRISTOPHER B. YORK[†]

Department of Aerospace Engineering, University of Glasgow, James Watt Building,
Glasgow, G12 8QQ, UK[‡]
c.york@aero.gla.ac.uk[§]
http://www.aero.gla.ac.uk/structures

Abstract

New design concepts are demonstrated for twenty-four classes of laminate, which have been derived as part of an ongoing study on the development of a unified approach to the characterization of coupled laminates. This article presents a description of each class of coupled laminate; the vast majority possessing coupling behaviour not previously identified in the literature. Coupled laminates have potential applications in the: design of aero-elastic compliant rotor blades or aircraft wing structures, by introducing tailored Extension-Twisting and/or Shearing-Extension coupling at the laminate level or; design of thermally activated morphing structures, by exploiting more complex coupling behaviour. Results are presented which demonstrate various mechanical coupling responses, including thermally induced curvature predictions resulting from a high temperature cure process. However, the main focus of this article concerns the identification of laminates possessing complex mechanical couplings that remain hygro-thermally curvature stable; also referred to as warp-free laminates. The number of solutions for each class of coupled laminate is given together with example stacking sequences. These laminates contain standard cross-ply and/or angle-ply combinations, although double angle-ply laminates are also considered, and correspond to any standard fibre/matrix system with a constant ply thickness throughout.

Keywords Coupled Laminates, Bending-Extension, Bending-Shearing, Twisting-Shearing, Standard Angle-ply and Cross-ply Laminates, Double Angle-ply Laminates, Lamination Parameters, Thermal response, Warp-free, Hygro-thermally Curvature Stable.

1. Introduction

This article is one of a series addressing a unified approach to the characterization of coupled composite laminates. The first article in the series presented a number of important classes of coupled laminate benchmark configurations that exhibit behaviour similar to conventional materials, such as metals, and against which all unique forms of laminate behaviour, arising from isolated and combined coupling effects, will be later characterized. These benchmark configurations included fully uncoupled Extensionally Isotropic Laminates and Fully Isotropic Laminates. A special class of uncoupled laminate, possessing concomitant or matching elastic properties in both extension and bending, was also presented; and commonly referred to as a Quasi-Homogeneous Orthotropic Laminate. All were shown to be sub-sets of a definitive list of Fully uncoupled Orthotropic Laminates (York, 2007, 2009), containing generally non-symmetric stacking sequences that are characterized in terms of angle- and cross-ply sub-sequence symmetries. Dimensionless parameters were given for each stacking sequence, from which the extensional (**A**), coupling (**B**) and bending (**D**) stiffness matrices are readily derived, together with expressions that relate the dimensionless parameters to the well-known lamination parameters.

The key focus of current article concerns the identification of laminates which possess complex mechanical couplings yet remain hygro-thermally curvature stable or warp-free. The identification of stacking sequence configurations which satisfy the hygro-thermally curvature stable condition will allow a broad range of exotic mechanical coupling attributes to be exploited without the complicating issue of thermal distortions, which are an inevitable consequence of the high temperature curing process. The design of aero-elastic compliant rotor blades with tailored extension-twist coupling (Winckler, 1985) is an example of one such laminate design that