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Optimisation of Composite Structures - Enforcing the Feasibility of Lamination Parameter constraints with Computationally-efficient Maps

T. Macquart[1], V. Maes[2], Marco T. Bordogna[3], A. Pirrera[4], P. M. Weaver[5]

Abstract

Composite materials are increasingly used in high performance structural applications because of their high strength and stiffness to weight ratios together with their significant tailoring capabilities. The stiffness of a monolithic laminate can be expressed as a linear combination of material invariants, one thickness variable, and twelve lamination parameters, which is an efficient alternative to using fibre angles as design variables. However, feasibility constraints originating from the interdependency between lamination parameters must be satisfied to obtain laminates with realistic stiffness properties. Currently, enforcing these feasibility constraints is a computationally intensive task. In this paper we propose to use normalised design variables that inherently map (i.e. correspond) to feasible lamination parameters, effectively removing the need to evaluate feasibility constraints altogether. To this end, linear and B-spline maps of the feasible lamination parameter subspace are proposed and evaluated. Results of 2D and 4D benchmark analyses and optimisation studies suggest that the proposed methodology does successfully provide an efficient means of achieving feasible results at lower computational costs.

Keywords: Composite Materials, Laminate, Structural Optimisation, Lamination Parameters, Maps

1. Introduction

Over the last decade numerous investigations highlighting the weight saving potential of composite materials have resulted in the steady incremental use of composites in industries. Composite materials offer greater tailoring capabilities and higher strength and stiffness to weight ratios than their metal counterparts. In particular, the superior tailoring potential of composites stems from the separation of structural (e.g. geometry) and material (e.g. fibre orientation) degrees of freedoms (D.O.Fs) in laminates, something that is not possible with isotropic materials.

Structural optimisation has played a pivotal role in demonstrating the tailoring capabilities offered by composite materials [1]. However, the large number of design D.O.Fs providing composite structures with great tailorability also results in a complex search space including both continuous and integer design variables [2], as well as new failure criteria. The size and shape optimisation methods previously developed for metals structure [3, 4] consequently proved to be insufficiently equipped to satisfactorily optimise composite structures. As a result, the optimisation of composite structure is often limited to a small design subspace in which laminates effectively behave like isotropic metals (i.e. quasi-isotropic laminates, also referred to as black metal).

The complex design space associated with composite structures has encouraged the development of new optimisation methods [5] and parameterisations [6]. Wherever metals or composites are used, structural

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