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Abstract

A structural analysis and an optimization method for anisogrid composite lattice shell structures is proposed, considering cylindrical structures simultaneously subjected to different external loads and multiple stiffness constraints. A discrete approach is used to exactly estimate the critical buckling load of the anisogrid lattice structure, independently of the buckling failure mode. The method makes use of a full FE parametric modeling technique able to manage all the geometrical parameters of the anisogrid composite lattice structure. Then an optimization procedure based on the genetic algorithm NSGA-II has been performed; it allows to analyze different alternatives in terms of geometrical variables, both continuous and discrete, driving the search towards the optimal solution in term of mass and conformity with all structural and stiffness constraints, aiming at the preliminary design of an actual structure. The practical usefulness and applicability of the proposed procedure to industrial cases was demonstrated through numerical examples where the anisogrid lattice structure was subjected to multiple external loads and stiffness constraints simultaneously applied.

Keywords: A. Carbon Fiber, B. Buckling, C. Finite element analysis (FEA), E. Filament winding, Genetic Algorithm Optimization

1. Introduction

The growing needs of lightweight and structural efficiency in aeronautic and aerospace industries brought to the development of a new design solution for grid structures: anisogrid composite lattice structures, highly capable of withstanding compression loads in conjunction with substantial stiffness features. These features allow to obtain important mass saving and cost reduction in reference to conventional aluminum components. The idea of grid structures realized with composite materials belong to Vasiliev et al. [1], initial studies on this topic took place in Russia during the early 80s with a research program that brought to the development of the first design and manufacturing methods. Successive papers about anisogrid composite lattice structures of the same authors shown progresses in this field [2, 3]: load-bearing parts such as rocket interstages, payload adapters and fuselage segments, characterized by high structural and mass efficiencies, were made by continuous filament winding which remains the most widespread fabrication technology. More recently, a new technology based on dry robotic winding of the lattice structure, followed by resin infusion under vacuum was demonstrated [4].

Anisogrid lattice structures can be found in the form of cylindrical or conical lattice shells, depending on the particular application. They are composed of a regular pattern of elementary lattice cells constructed by two systems of unidirectional composite ribs with rectangular cross-section: two sets of helical ribs, inclined with respect to the meridian curve of the shell with the same angle but in opposite directions and hoop ribs. Geometrical schemes made of hexagonal or triangular cells are normally constructed through cells' repetition alongside the meridian curve of shell and around its axis. The particular choice of the elementary lattice cell type affects the strength and the stiffness of the anisogrid lattice structure. When needed, a skin, external or internal to the ribs and co-cured with them, without important structural characteristics but with a functional role is added to the lattice shell.

Different sizing and optimization methodologies can be found in literature, which concern with cylindrical and conical lattice shells and both typologies of cells. Many of these methods consider the anisogrid lattice structure as a continuum shell and the stiffness properties of the ribs are distributed over the medium surface of the equivalent shell applying smearing techniques [5–8] meanwhile discrete approaches based on the finite element method are less common [9, 10].

The minimization of safety factors belongs to the former category of approaches and it was proposed by Vasiliev et al. for cylindrical [5] and conical shells [11]. It represents an analytical solution to the problem of constrained structural optimization of an axially compressed anisogrid composite lattice structure without an additional skin.

Totaro and Gürdal expanded this approach [6], including the axial stiffness requirement of the anisogrid lattice structure through a numerical optimization routine capable of parametrically exploring configurations with different number of helical ribs to find the solution which satisfies all constraints. Furthermore, a formulation of the local buckling coefficient which

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