Design, analysis and optimization of anisogrid composite lattice conical shells

Valerio G. Belardi, Pierluigi Fanelli, Francesco Vivio

PII: S1359-8368(18)30603-6

DOI: 10.1016/j.compositesb.2018.05.036

Reference: JCOMB 5706

To appear in: *Composites Part B*

Received Date: 22 February 2018

Revised Date: 3 May 2018

Accepted Date: 24 May 2018

Design, analysis and optimization of anisogrid composite lattice conical shells

Valerio G. Belardi[a], Pierluigi Fanelli[b], Francesco Vivio[a,*]

[a] Department of Enterprise Engineering - University of Rome Tor Vergata, Via del Politecnico, 1, 00133, Rome, Italy
[b] DEIM, University of Tuscia, Largo dell'Università, 01100 Viterbo, Italy

Abstract

A methodology for structural analysis and optimal design of conical anisogrid composite lattice shell structures subject to different external loads concurrently applied and multiple stiffness constraints is presented. The critical buckling load of the anisogrid lattice conical structure is exactly assessed, independently of the buckling failure mode, by means of a discrete approach. The method makes use of a full FE parametric modeling technique able to manage all the geometrical parameters of the anisogrid composite lattice structure. Additionally, the genetic algorithm NSGA-II is employed to set up an optimization procedure which allows to analyze different sets of geometrical variables, both continuous and discrete, to reach the optimal solution in terms of mass amount and fulfilling of structural and stiffness requirements, aiming at the preliminary design of an actual structure. Numerical case-studies are outlined in order to demonstrate the practical usefulness and versatility of the proposed procedure to industrial cases where the anisogrid lattice conical structure undergoes multiple external loads and various stiffness constraints must be satisfied.

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

1. Introduction

Anisogrid composite lattice structures are composite grid-structures which represent an effective technical solution in the aeronautic and aerospace fields for applications that require structural components characterized by high load-bearing and stiffness capabilities as well as a low mass amount.

This kind of structures are utilized in all the principal space programs, such as the Russian one, in the framework of which the early studies were carried out [1–3]. Further research programs took place in the USA, regarding both the structural behavior [4] and the manufacturing process [5] of composite grid-structures. The interest of the Japan Space Agency about this topic is likewise growing, aiming to the production of a future launchers generation [6, 7].

Launcher components such as rocket interstages, payload adapters and fairings have been realized making use of anisogrid structures and the possibility of employing them in the production of fuselage barrels is further being studied [8].

Anisogrid lattice structures consist of a repetitive arrangement of unidirectional helical and hoop composite ribs, mutually intersecting, wherein an elementary lattice cell can be identified and considered as the fundamental unit of the anisogrid structure. Anisogrid lattice structures can be found in the form of cylindrical or conical lattice shells, depending on the particular application. Hexagonal and triangular elementary lattice cells are commonly employed: in the first one, the hoop ribs divide equally the helical ribs segments spanning between adjacent intersection points; in the latter, the hoop ribs crosses the helical ribs in proximity of their intersection points. Furthermore, in [9] the skin-added X-lattice composite structure is presented: this new design solution avoids the use of hoop ribs introducing an external thin skin, with fibers in the hoop direction, to increase the mechanical performance. The external skin contributes to prevent buckling modes characterized by local rotations of the helical ribs.

One of the main issues linked to this technology is the connection of its composite endings to metallic flanges through demountable joints; this issue is currently studied by the same authors [10–12].

According to the design process, the goal is the identification of the optimal anisogrid composite lattice structure configuration, i.e. the layout with the lowest mass amount capable of fulfilling the set of constraint conditions which in general concern with static strength, buckling resistance and stiffness requirements. Different optimization methodologies can be found in literature, which concern with cylindrical and conical lattice shells and both typologies of cells. These methodologies can be divided in continuous approaches and discrete approaches.

The continuous approaches to the structural analysis of anisogrid lattice structures are based on smearing techniques, i.e. the lattice shell is treated as a continuum media: the stiffness properties of an equivalent orthotropic shell are obtained from the anisogrid lattice structure ones according to a particular criterion. These methods have been used for different purposes, such as the preliminary design of axisymmetric lattice shells reaching analytical closed form solutions regarding the optimal geometrical configuration of both cylindrical and lattice conical shells under axial compressive load [1, 13]. A numerical optimization procedure was used for anisogrid lattice

*Corresponding author. Tel.: +39 06 72597123.
Email address: vivio@uniroma2.it (Francesco Vivio)