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Bi-functional optimization of actively cooled, pressurized hollow sandwich cylinders with prismatic cores

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Abstract

All metallic, hollow sandwich cylinders having ultralight two-dimensional (2D) prismatic cores are optimally designed for maximum thermo-mechanical performance at minimum mass. The heated cylinder is subjected to uniform internal pressure and actively cooled by forced air convection. The use of two different core topologies is exploited: square- and triangular-celled cores. The minimum mass design model is so defined that three failure modes are prevented: facesheet yielding, core member yielding, and core member buckling. The intersection-of-asymptotes method, in conjunction with the fin analogy model, is employed to build the optimization model for maximum heat transfer rate. A non-dimensional parameter is introduced to couple the two objectives—structural and thermal—in a single cost function. It is found that the geometry corresponding to maximum heat transfer rate is not unique, and square-celled core sandwich cylinders outperform those having triangular cells. The eight-layered sandwich cylinders with square cells have the best overall performance in comparison with other core topologies. Whilst a sandwich cylinder with shorter

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length is preferred for enhanced thermo-mechanical performance, the influence of the outer radius of the cylinder is rather weak.

Keywords: Cellular materials; Pressurized hollow cylinder; Active cooling; Optimal design; Multifunction

1. Introduction

All metallic sandwich panels with open, periodic cellular cores have recently emerged as one of the most weight efficient structures, such as three-dimensional (3D) truss cores and two-dimensional (2D) prismatic cores; see, for example, Hutchinson and He (2000), Wicks and Hutchinson (2001), Valdevit et al. (2004, 2006a, b), and Liu et al. (2006). Concomitantly, the open core topologies provide access for multifunctional applications, such as simultaneous load bearing and active cooling (Kim et al., 2004; Tian et al., 2004; Lu et al., 2005; Raskie, 2006); blast resistance (Xue and Hutchinson, 2003, 2006); vibration and noise control (Lu et al., 2000; Ruzzene, 2004); and structural actuation (Hutchinson et al., 2003; Wicks and Hutchinson, 2004).

Prior work has tended to focus on applications involving dynamic shock-type loadings, and for that class of problems the benefits of sandwich construction have been well established. Recently, a statically loaded cylindrical shell with sandwich walls subjected to internal pressure loading has been optimized by Liu et al. (2007). Five different core topologies are considered: Kagomé truss, single-layered pyramidal truss, double-layered pyramidal truss, single-layered corrugated core and double-layered corrugated core. Note that the deformation of most of these structures is governed by cell wall/ligament stretching, as opposed to bending commonly found in stochastic metal foams. Although the problem considered by Liu et al. (2007) is well-known to be not bending dominated, their results clearly demonstrate the significant benefit from sandwich construction relative to hollow cylinders having monolithic walls, which is interesting and intriguing.

Built upon the work of Liu et al. (2007), the study presented in this paper focuses on the bi-functional performances of 2D cellular metallic cores, namely, hollow sandwich cylinders subjected to a combination of internal pressure and thermal loading are optimized. Potential applications include cylindrical combustion chambers for rocket and missile propulsion, as well as airplane and land-based vehicle engines with the use of turbines and pistons (Raskie, 2006).

Combustion chambers are traditionally enclosed in monolithic structures that must withstand the high pressures and temperatures of combustion. A combustion engine that is both structurally lighter and more efficient in heat dissipation can significantly reduce weight and energy consumption (Raskie, 2006). It is anticipated here that using sandwich constructions with lightweight cellular topologies may improve the engine performance. Specifically, combining these topologies with current engine design in the form of a hollow sandwich-walled cylinder (as shown in Fig. 1) would greatly decrease weight while allowing for active air convection cooling across the open passages. The aim is to optimize the topological and geometric parameters of the sandwich construction for maximum bi-functional performance.

Two different prismatic core topologies are proposed for the hollow sandwich-walled cylinder, namely, square- and triangular-celled cores (see Fig. 2). The structural and