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Vibroacoustics of 2D gradient auxetic hexagonal honeycomb sandwich panels

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ABSTRACT

This paper describes the vibroacoustic behavior of sandwich panels with a novel core topology made from 2-dimensionally gradient auxetic hexagonal honeycombs. The 2D gradient core enables a tailoring of localized mechanical properties of the sandwich structure in different regions of the panel. A homogenized finite element modeling has been used to initially determine the mechanical properties of the structures. The natural frequencies and the radiated sound power level of the sandwich plate with the homogenized properties have been calculated and verified with those obtained from a full-scale detailed model of the sandwich structure. The geometry of the 2-dimensionally gradient auxetic core has been then optimized using two different techniques in order to minimize the radiated sound power level over the frequency range of 0 to 200 Hz. The optimized design of the 2-D gradient core shows a remarkable reduction of the radiated sound power level for the sandwich structure when taking into account the mass of the panels. The results of this study provide new insights about the vibroacoustic behavior of hexagonal auxetic sandwich structures with complex core geometry.

1. Introduction

Honeycomb sandwich structures possess outstanding out-of-plane mechanical properties, which are directly related to their shape and topology [1]. Cellular solids with honeycomb structure can be used as a sandwich core materials in different engineering applications, such as automotive lightweight structures and biomedical [2–4]. A typical example of cellular solid as a sandwich core is the conventional hexagonal honeycomb, in which each unit cell is made of ribs with the same length and an internal cell angle of 30° [5]. However, in recent years synthetic materials possessing negative Poisson’s ratio (auxetic) have been also proposed [6–9]. In contrast to conventional materials, these solids called “auxetic” expand in all direction when subjected to uniaxial loading [10]. This behavior is usually linked to specific microstructural deformation mechanisms, and can be observed in several types of auxetic structures such as re-entrant, chiral, and rotating units structures [11–17]. Moreover, one of the iconic examples of auxetic materials is the hexagonal center-symmetric re-entrant configuration [18,19] that provides an increase in anisotropic bending stiffness, which can be useful in vibration [20] as well as for enhanced flatwise compressive strength in reinforced butterfly cores [21]. The out-of-plane deformation of regular honeycombs shows anticlastic or saddle-shaped curvature [22–25]. On the other hand, structures with negative Poisson's ratio behavior exhibit synclastic curvature when subjected to out-of-plane bending which makes them an excellent candidate to be used in a complex out-of-plane geometry [4,22,24,26].

Representative unit cells have been widely used to model mechanical properties of composite materials and sandwich structure [16,27,28]. The same concept can be applied in auxetic cellular configurations. The structure can be considered as a periodic repetition of the unit cell. The homogenized mechanical properties can also be defined by the geometrical parameters and the core properties of the repeating unit cells.

Auxetic materials have been evaluated for various applications. Auxetic cellular structures have been used to prototype morphing wings [29,30]. On the same topic, Airoldi et al. developed advanced applications of auxetic chiral structures in composite aero structures designs [31]. In another research activity the wave propagation in sandwich

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panels with periodic auxetic core was investigated by Ruzzene et al. [32]. The microstructure configurations examined in the above cited research tessellate periodically in the plane. The cellular structure is therefore made of cells having the same geometry in any part of the structure. It is however possible to produce this cellular structure with a gradient configuration. The configuration in this gradient topology is made of a continuous distribution of unit cells with compatible geometry, but having a single variable parameter (like the internal cell angle or internal thickness) [33–35]. In gradient configuration, varying distribution of stiffness and deformation can be achieved by using a gradient cellular structure. For center-symmetric configurations, Lim introduced a varying gradient cellular topology in which the internal cell angle at each row was changing [36]. Honeycomb structures made with thickness-gradient layouts have been modeled and tested by Lira and Scarpa [37]. In particular, the cellular structures made with gradient thickness have offered an increased specific shear stiffness compared to conventional configurations with same cell shape. The flexural properties and failure behavior of sandwich structures with auxetic angle gradient core have been explored by Hou et al. [38].

Several papers have been devoted to the investigation of the vibrational and acoustic behavior of sandwich structures with normal or gradient cellular core. The vibrational characteristics of re-enterant auxetic honeycomb have been investigated by Scarpa and Tomlinson [20]. Lim [39] and Maruszewski et al. [40] have investigated the vibration of auxetic circular and rectangular plates. In another work Shiyin et al. have studied the vibration transmission and isolation performance of trichiral structures with uniform and gradient geometry [41]. Lira et, al have used an auxetic gradient cellular as potential cores for aeroengine fan blades to reduce the dynamic response for the first three fundamental natural frequencies [42].

One of the key parts in the design of the passive noise control compliant structure is the optimization of the structures with respect to their acoustical and structural properties (including, radiated sound power and root mean square level of the structural particle velocity). Applications and methods of structural acoustic optimization with respect to passive noise control have been reviewed by Marburg [43]. Ranjbar et al. applied different optimization methods to minimize the radiated sound power level of a simple steel rectangular plate [44–50]. Geometrical parameters of normal and gradient auxetic cellular cores can be tailored to have desired mechanical and density properties. Therefore, they can be a suitable platform to design structural panels with optimized mechanical and vibroacoustic performance over a range of frequency bandwidths. In a different study, Ranjbar et al. [33], studied the effect of geometrical parameters of the auxetic core on radiated sound power level of sandwich panel structures. Some simple optimization techniques (such as random and first order optimization method) have been used in particular to minimize the radiated sound power level for a sandwich panel with a one-dimensional gradient auxetic core.

In the present paper we however investigate the effect of the topology of a novel two-dimensional gradient auxetic honeycomb core on the radiated sound power level. Moreover, two well-known and robust optimization methods, i.e. the genetic algorithm (GA) and the Method of Moving Asymptotes (MMA) [51,52] are applied to minimize the radiated sound power level from the sandwich structure. To perform this analysis a direct software coupling between MATLAB and ANSYS (Finite Elements) software platforms has been developed. To the best of the Author's knowledge, a 2D-gradient cellular auxetic topology has not been thoroughly evaluated for vibroacoustics applications. Moreover, the use of a combined GA-MMA optimization approach is a first in the field of vibroacoustics.

In the following section the mechanical behavior of hexagonal cores is firstly investigated using analytical techniques.

2. Determination of mechanical properties of auxetic hexagonal sandwich panel

An analytical model has been used to calculate the mechanical properties of auxetic hexagonal honeycombs. Gibson and Ashby [5], have used an analytical methodology to find mechanical properties hexagonal honeycombs. Later, Lira et al. [42] and Ranjbar et al. [33] have used the same analytical method which defines mechanical properties of hexagonal honeycombs based on three non-dimensional parameters $\alpha = \frac{h}{L}, \beta = \frac{t}{L}, \gamma = \frac{b}{L}$ and the angle θ. Fig. 1, demonstrates a representative unit cell of the auxetic hexagonal honeycomb structure and its geometrical parameter.

The mechanical properties of the honeycomb core plate are modeled by an equivalent orthotropic material. The compliance matrix [S] for an orthotropic material is defined as below, in which the engineering constants E_x, E_y, E_z, G_{xy} and G_{xz} can be found from Gibson and Ashby [5] or Lira et al. [42]. Considering Cellular Material Theory [5], the out-of-plane Poisson's ratios υ_{xz} and υ_{yz} can be assumed approximately zero. Moreover, the other transverse Poisson's ratios υ_{zx},υ_{zy} are assumed to be equal to Poisson's ratio of the core material, υ_c [5,42].

$$[S] = \begin{bmatrix} \frac{1}{E_x} & -\frac{\upsilon_{xy}}{E_y} & -\frac{\upsilon_{xz}}{E_z} & 0 & 0 & 0 \\ -\frac{\upsilon_{yx}}{E_x} & \frac{1}{E_y} & -\frac{\upsilon_{yz}}{E_z} & 0 & 0 & 0 \\ -\frac{\upsilon_{zx}}{E_x} & -\frac{\upsilon_{zy}}{E_y} & \frac{1}{E_z} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{xz}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{yz}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{xy}} \end{bmatrix} \quad (1)$$

The formulations given in [5] for calculation of the mechanical

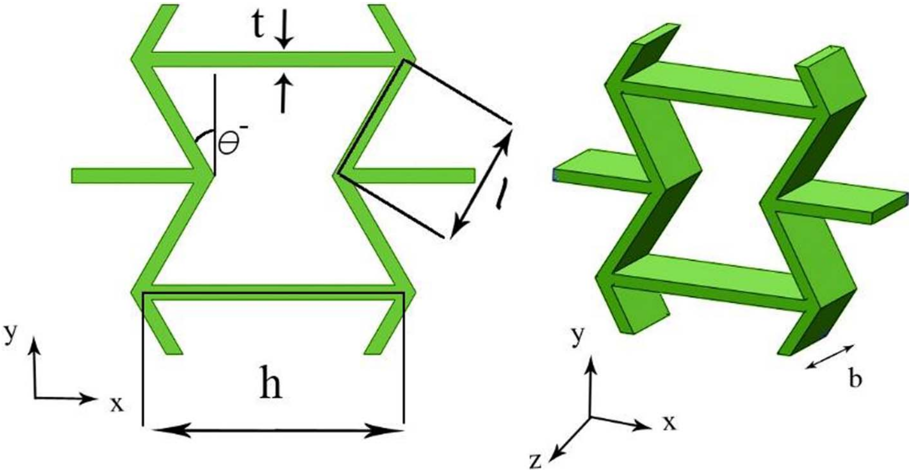

Fig. 1. A representative unit cell (RUC) of the auxetic hexagonal honeycomb.