Optimization of the vibro-acoustic indicators of honeycomb panels

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ABSTRACT

Modern design in the aerospace industry requires the use of lightweight structures, ensuring security and comfort and responding adequately to the environmental demands. In particular, a great deal of interest is focused on the question of noise reduction, because lightweight structures have generally poor sound insulation properties.

The aim of the present work is to find a periodic optimal geometry of the honeycomb core. The suggested design strategy reported here is an optimization procedure involving tow scales: the meso-scale for the unit cell of the honeycomb panel and the macro-scale for the whole panel. To this purpose, an analytical homogenization technique was developed to determine the effective properties of the honeycomb structure along with a comparison with existing models. Also, a sensitive analysis in terms of the geometrical parameters of the unit cell has been conducted. Then, the modal density of honeycomb panel was predicted using the macro homogenized parameters.

1 INTRODUCTION

Honeycomb core sandwich panels are widely used in designing the structure of the aerospace industry. These panels typically feature orthotropic alveolar cores bonded to high modulus laminate skins. Generally, commercial varieties of honeycomb core sandwich panels are optimized for mechanical and weight constraints. As a result of this, a sandwich panel can be lightweight and designed to carry high mechanical loads. However, it tends to be poor when it comes to acoustic attenuation. To address this issue, several attempts have been made to identify the optimal sandwich plans that balance mechanical and acoustic properties. Among these attempts, the following references [1-3] have developed a methodology in order to maximize the transmission loss of these types of panels.

In the present paper, an optimization methodology was proposed to reduce the modal density (n) for the honeycomb sandwich panels. The modal density was predicted by using the analytical model established by Renji [4], which takes into account the shearing effect of the core structure. To predict the modal density, the effective properties of the honeycomb sandwich structure are required. For this purpose, the effective properties were obtained by analytical homogenization techniques by exploiting the meso-scale for the unit cell of the honeycomb panel and the macro-scale of the whole panel. Thereafter, a sensitivity analysis in terms of the geometrical and material parameters of the unit cell has been conducted.

1. FORMULATION OF THE PROBLEM

1.1 Optimization Model Formulation

The modal density of honeycomb sandwich panels is investigated in a large number of papers. Among the first formulation of the modal density for isotropic sandwich panels is developed by Wilkinson [5]. Later, a study was carried out by Erickson [6] to investigate the effect of the anisotropy of the core on the modal density. The theories suggested by the latter two authors are compared to experiments by Clarkson [7].

Experimental and analytical modal density for honeycomb sandwich panels, used in some applications, have been reported in the reference [4]. The study done in the reference [8], a summary of different theories for the modal density behavior of honeycomb sandwich panels has been reported.

The expression for the modal density of a honeycomb panel with an isotropic face sheet is written as follows:

$$n(f) = \frac{\pi ab M_p f}{N}\left\{1 + \left(M_p^2\omega^4 + \frac{4M_p\omega^2N^2}{D}\right)^{-\left(\frac{1}{2}\right)}\left(M_p\omega^2 + \frac{2N^2}{D}\right)\right\} \quad (1)$$

Where:

- a b is the panel surface area
- D is the section bending stiffness,
- Mp is the build-up panel mass/area
- N is the shear stiffness

1.2 Optimization Model Formulation

Optimization methods are mainly used in engineering design activities to achieve a competitive design, which optimize (i.e. either minimize or maximize) a certain objective by satisfying a number of constraints. The first step in an optimal design is to formulate the problem by writing the mathematical functions relating to the objective and constraints [9]. For this study, the optimization problem is defined in the following form:

$$\begin{aligned} &Minimize && f(x) && \\ &subject\ to && g_i(x) \geq 0, && i = 1,2,\dots,I; \\ & && h_j(x) = 0, && j = 1,2,\dots,J; \\ & && x_k^l \leq x_k \leq x_k^u\ , && k = 1,2,\dots,N. \end{aligned} \quad (2)$$

Where $\boldsymbol{f}(\boldsymbol{x})$ is the objective function. $\boldsymbol{g_i}(\boldsymbol{x})$ is the equality constraint. $\boldsymbol{h_j}(\boldsymbol{x})$ is the inequality constraints. While $\boldsymbol{x}$ is the variable vector, represents a set of variables x_i.

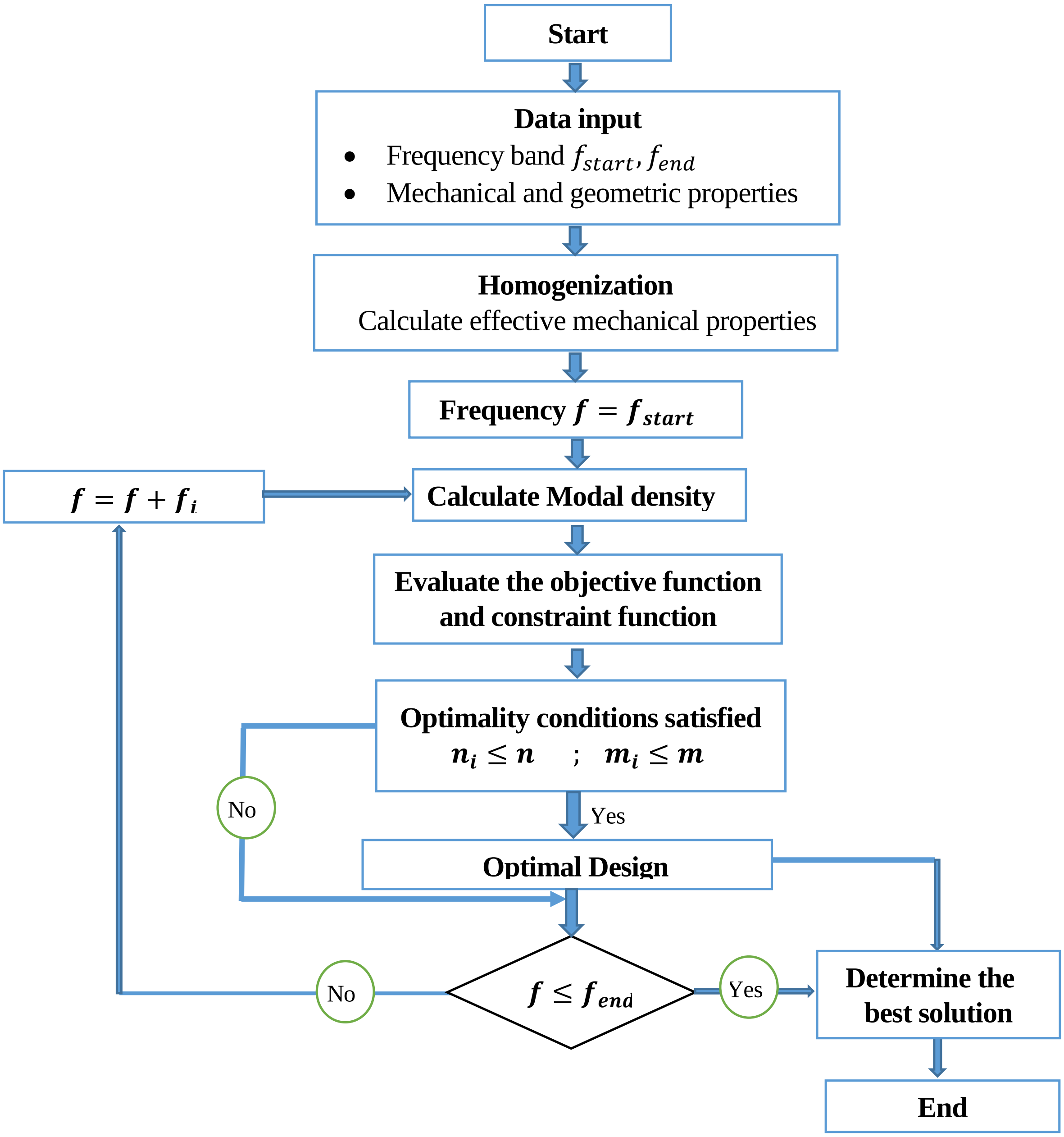

Figure 1. The current optimization methodology of the honeycomb modal density.

2 RESULTS

For the analyses of the present study, the hexagonal-cell core sandwich panel is considered, as illustrated in the figure (1). The honeycomb core is made of Nomex, whose properties and dimensions are summarized in the table (1). On the other side, the face-sheet material is made of Aluminum, whose properties are $E = 72{,}5$ GPa, $\nu = 0.33$, and the skin thickness $t_f = 0.076$ mm.

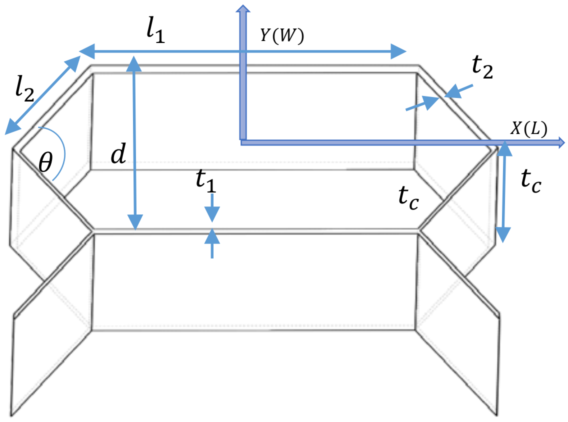

Figure 2. The geometrical parameters of the honeycomb cell.

Core: Nomex honeycomb core	
Core density	$1{,}38\ 10^3$kg/m3
Core thickness	20 mm
t_2, t_1,	0,079 mm, 0,159 mm
l_1, l_2, $\boldsymbol{\theta}$	4,9 mm, 1,63 mm, $\frac{\pi}{12}\ rad$

Table 1. The geometrical core values of the honeycomb cell.

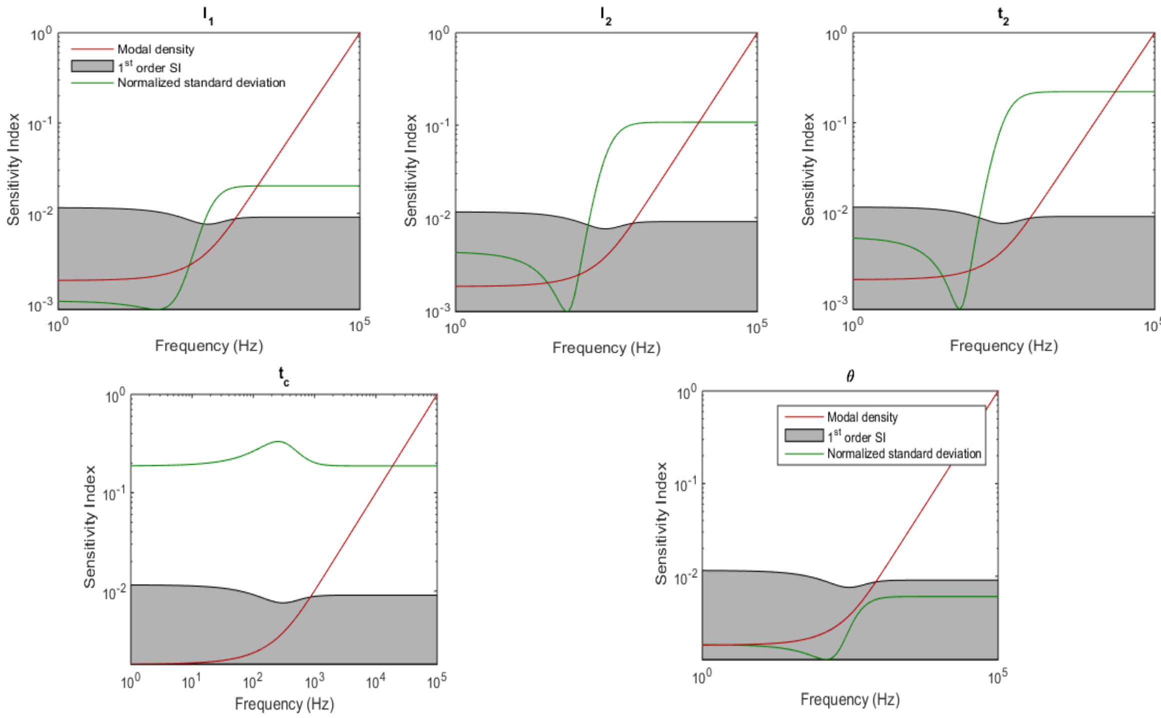

Figure 3. The sensitivity results of geometrical honeycomb panel

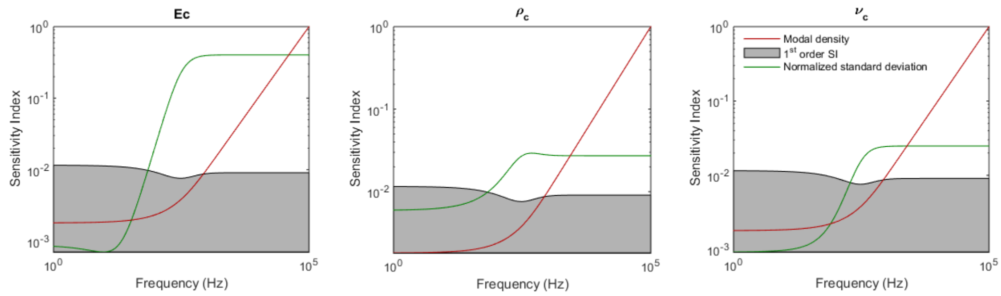

Figure 4. The sensitivity results of material honeycomb panel

The figures (3) and (4) represent the sensitivity analysis done for a honeycomb sandwich panel illustrated in the figure (1). The study shows that for 1% of variation of each honeycomb properties, in the medium and high frequency, the effect of the properties is very considerable with respect to the low frequency.

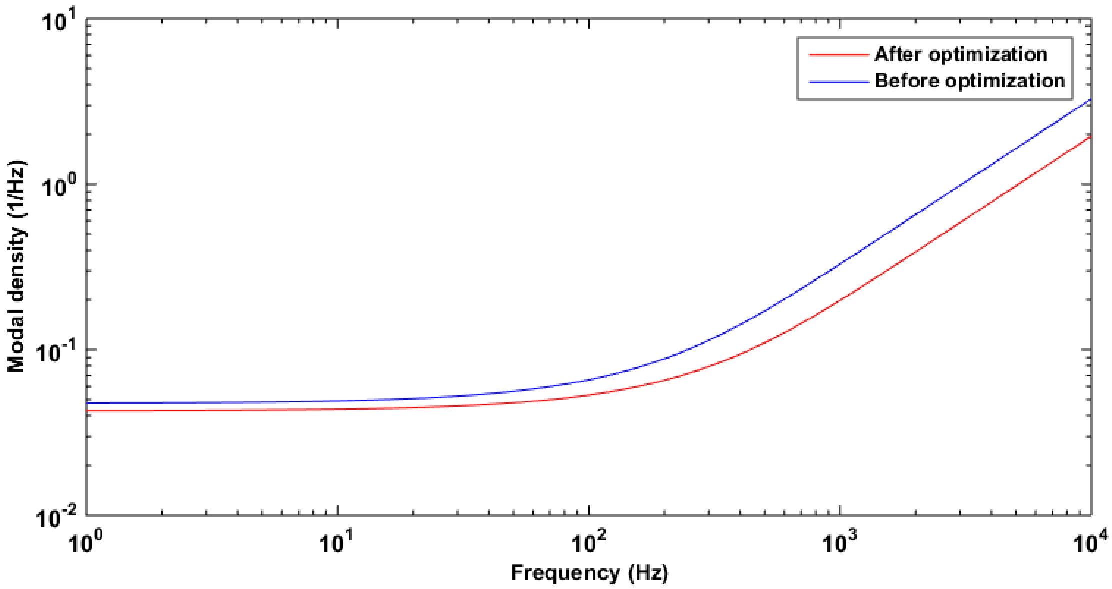

Figure 5. The comparison between the optimal modal density and the original modal density

By following the optimization methodology presented in the figure (1), a comparison of the non-optimal and optimal modal density is depicted in the figure (5). The optimization study is done under two constraints the mass and the stiffness of the honeycomb panel. These two constraints have to remain constant after the optimization study. The red modal density curve in the figure (5) presents the minimum modal density obtained by the optimal variable design.

3 CONCLUSION

The present optimization study was based on the modal density predicted by Renji's model. This modal density takes into account the transverse shear effect. The sensitivity analysis of the honeycomb sandwich panel showed that the effective properties of the panel, obtained by different homogenization techniques, have considerable influence on the modal density whether in the medium or the high frequency range. This sensitivity study allows us to identify the most sensitive properties which we should focus on them. The optimization of these sensitive core parameters resulted a minimum modal density with respect to the previous one.

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