ANALYSIS OF MECHANICAL PROPERTIES OF COMPOSITE SANDWICH PANELS WITH FILLERS

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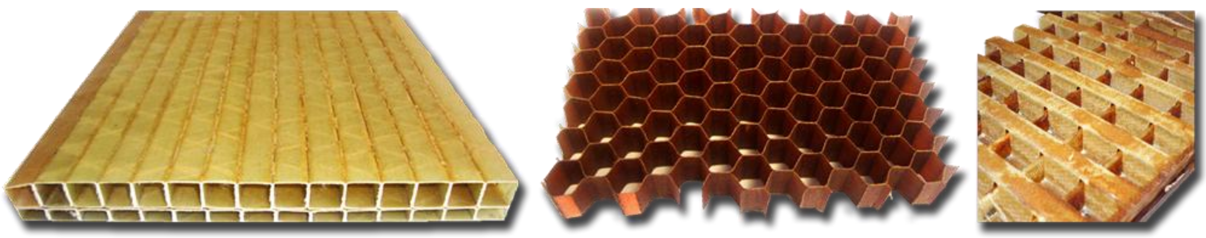
Abstract

This work is dedicated to experimental-theoretical analysis of mechanical properties of sandwich panels made of fibrous polymer composite materials with different types of core: tubular, honeycomb and cellular.

1. Introduction

Today sound-absorbing acoustic sandwich panels (acoustic liners) made of composite materials are vital elements of many modern aircraft turbojet engines. Different types of core are used for sandwich panels – tubular, honeycomb or cellular types (figure1). Earlier single-layer liners with perforation were used, but now double-layer liners are used to enhance acoustic damping. Also a combination of different types of fillers (cores) can be used at the same time. In addition to noise requirements acoustic liners must satisfy many other design constraints. So the providing of strength of composite sandwich panels in the nacelle of engine under different loading conditions is very important.



a *b* *c*

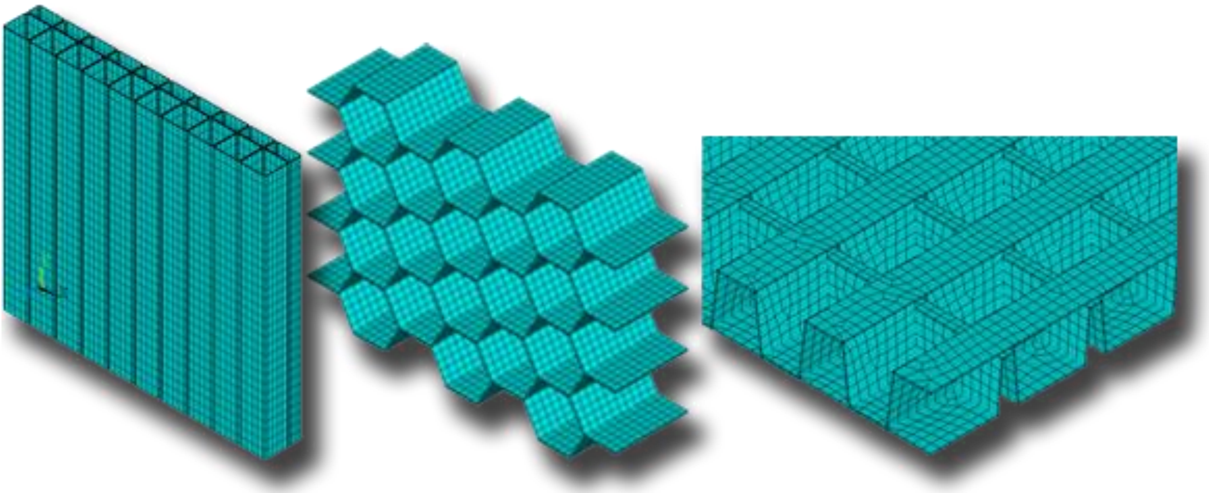
Figure 1. Types of fillers: tubular (a), honeycomb (b), cellular (c).

The behavior of honeycomb structures was investigated, for example, in [1-3] using the finite element method (FEM). Today the most researches are devoted to mechanical behavior of hexagonal cell filler (honeycomb-core) made of metallic materials and based on the theory of strength of materials with some assumptions [4-6]. The present work is dedicated to experimental-theoretical prediction of effective mechanical properties of sound-absorbing sandwich panels and different types of fillers (cores) made of fibrous polymer composite materials.

2. Effective elastic properties of fillers

The finite element method is a powerful analysis tool for solving various engineering problems. However, a detailed representation of honeycomb or cellular cores is not suitable for large-scale models due to computational difficulties. To achieve the efficiency of the numerical simulation the honeycomb or cellular fillers are usually replaced by equivalent homogeneous volumes with effective orthotropic properties [7]. Orthotropic material is defined by nine independent elastic constants: E_x, E_y, E_z, ν_{xy}, ν_{yz}, ν_{xz}, G_{xy}, G_{yz}, G_{xz}. It is necessary to make six numerical experiments to obtain effective properties of filler: three tensile tests to determine the Young's modulus and Poisson's ratio, and three shear tests to determine the shear modulus.

The numerical solution of the problem of finding effective elastic properties of fillers was performed with the use of the ANSYS software. Three-dimensional models of fillers with different structures were created. Shell281 finite elements were used for meshing of honeycomb and cellular cores and Solid186 elements – for tubular core (figure 2). To perform the numerical experiment we need to select a representative area for which mechanical characteristics will be determined.



a b c

Figure 2. Finite element models of fillers: a - tubular, b - honeycomb, c - cellular.

Effective elastic properties of fillers - Young's modulus E_x^*, E_y^*, E_z^*, shear modulus G_{xy}^*, G_{yz}^*, G_{xz}^* and Poisson's ratio ν_{xy}^*, ν_{yz}^*, ν_{xz}^* - were calculated by the following equations:

$$\begin{gathered} E_x^* = \frac{\langle \sigma_x \rangle}{\varepsilon_x^*},\ E_y^* = \frac{\langle \sigma_y \rangle}{\varepsilon_y^*},\ E_z^* = \frac{\langle \sigma_z \rangle}{\varepsilon_z^*} \\ G_{xy}^* = \frac{\langle \tau_{xy} \rangle}{\gamma_{xy}^*},\ G_{yz}^* = \frac{\langle \tau_{yz} \rangle}{\gamma_{yz}^*},\ G_{xz}^* = \frac{\langle \tau_{xz} \rangle}{\gamma_{xz}^*} \\ \nu_{xy}^* = \left|\frac{\varepsilon_y^*}{\varepsilon_x^*}\right|,\ \nu_{yz}^* = \left|\frac{\varepsilon_z^*}{\varepsilon_y^*}\right|,\ \nu_{xz}^* = \left|\frac{\varepsilon_z^*}{\varepsilon_x^*}\right| \end{gathered} \tag{1}$$

where strain was initially defined (kinematic loading), and averaged stresses $\langle \sigma_i \rangle$, $\langle \tau_{ij} \rangle$ were calculated by the equations:

$$\langle \sigma_i \rangle = \frac{\sum_{k=1}^{n} (\sigma_i)_k V_k}{V_m + V_v},\ \langle \tau_{ij} \rangle = \frac{\sum_{k=1}^{n} (\tau_{ij})_k V_k}{V_m + V_v} \tag{2}$$

where n – amount of finite elements;$\langle\sigma_i\rangle_k$, $\langle\tau_{ij}\rangle_k$– stresses at the *k-th* finite element; V_k – volume of the *k-th* finite element; V_m – volume of material, V_v – volume of voids.

Table 1 presents the calculated effective elastic properties of fillers made of fiberglass.

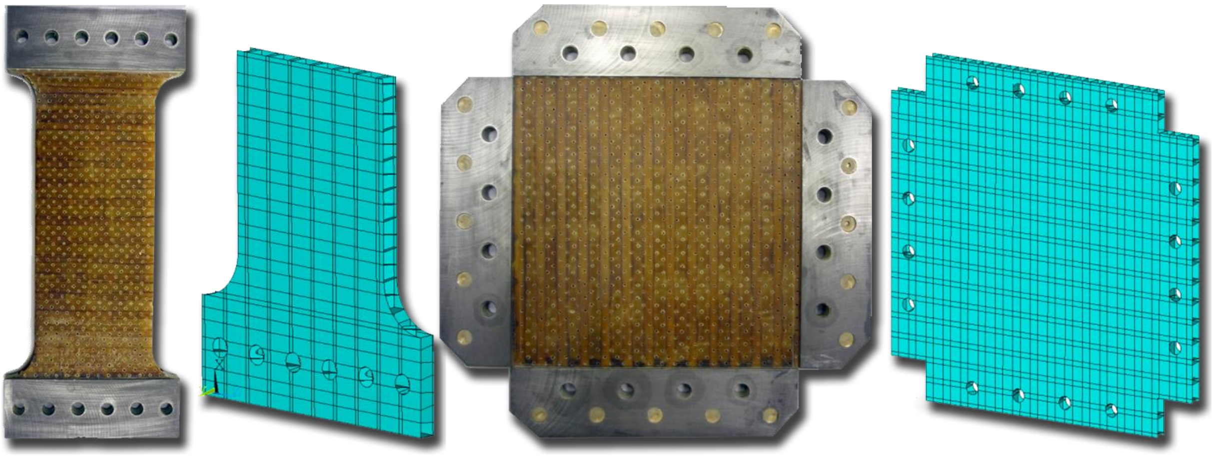
Type of filler (core)	E_x^* **MPa**	E_y^* **MPa**	E_z^* **MPa**	ν_{xy}^*	ν_{yz}^*	ν_{xz}^*	G_{xy}^* **MPa**	G_{yz}^* **MPa**	G_{xz}^* **MPa**
Tubular	307,1	2066,0	188,3	0,03	0,21	1,3	160,4	316,2	6,7
Honeycomb	1,2	1,05	880,8	1,06	2,12e-4	1,92e-4	0,28	53,8	108,8
Cellular	1141,8	270,2	613,5	1,61e-3	0,06	0,17	50,8	73,6	10,1

Table 1. Effective elastic properties of fillers made of fiberglass.

3. Effective elastic properties of sandwich panels with fillers

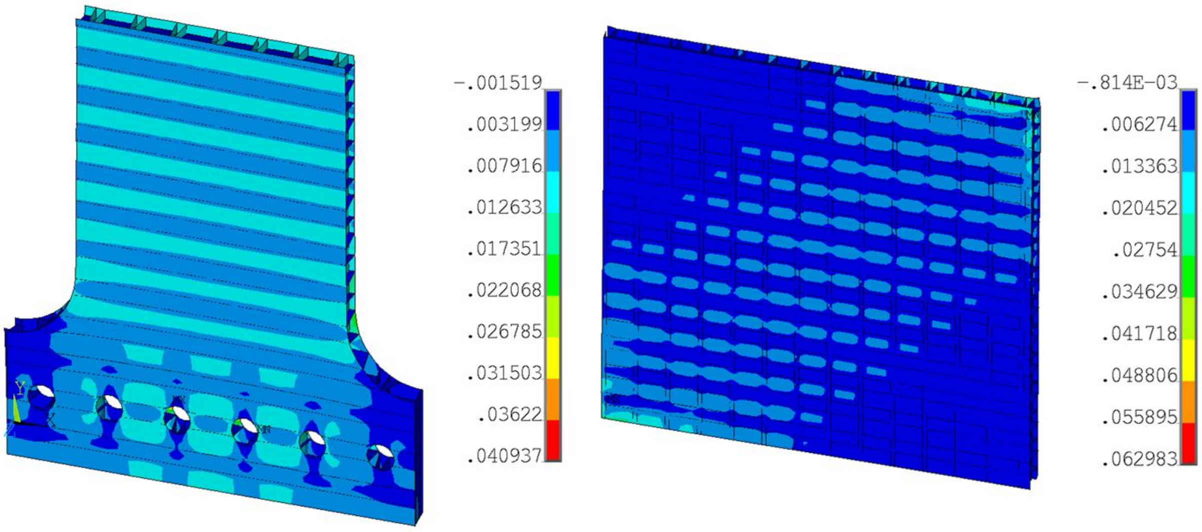
To estimate the effective elastic properties of sound-absorbing acoustic sandwich panels (acoustic liners), specimens with perforation for uniaxial tension and shearing tests were conducted. Also three-dimensional computer models of panel samples for tension and shearing test simulations were created (figure 3).

As a result of the numerical simulation by ANSYS software, stress and strain fields were obtained. Figure 4 shows the calculated axial and shear stresses in the samples of panel with cellular core under load of 1N. The stress-strain analysis allowed us to determine the averaged stresses in the samples and effective elastic modulus of acoustic liners.



a b

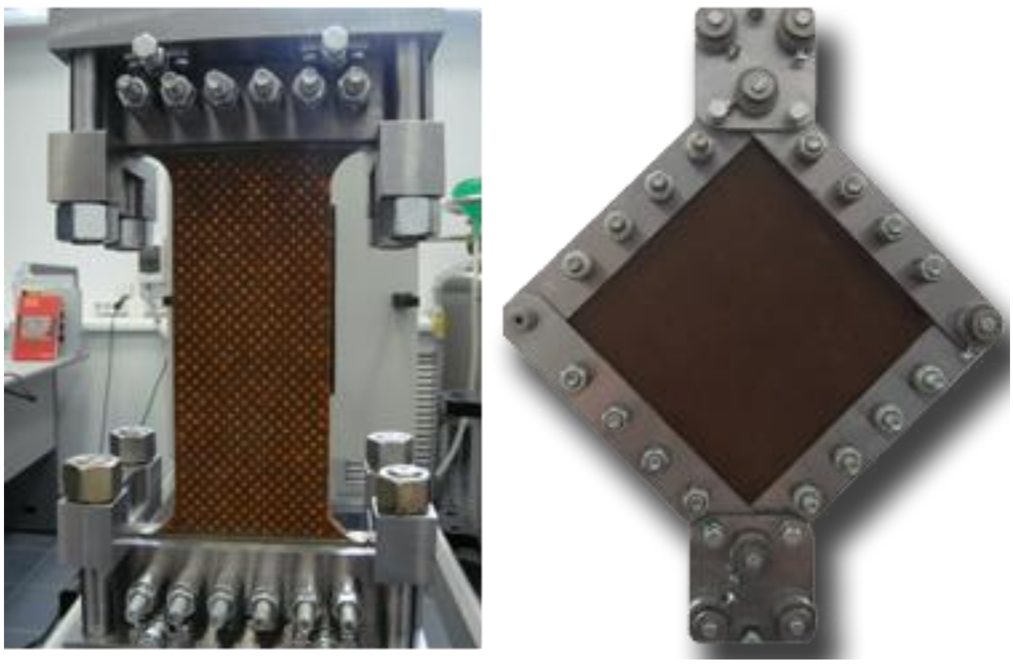
Figure 3. Sandwich panel samples and 3-D models for uniaxial tension (a) and shearing (b) tests.



a b

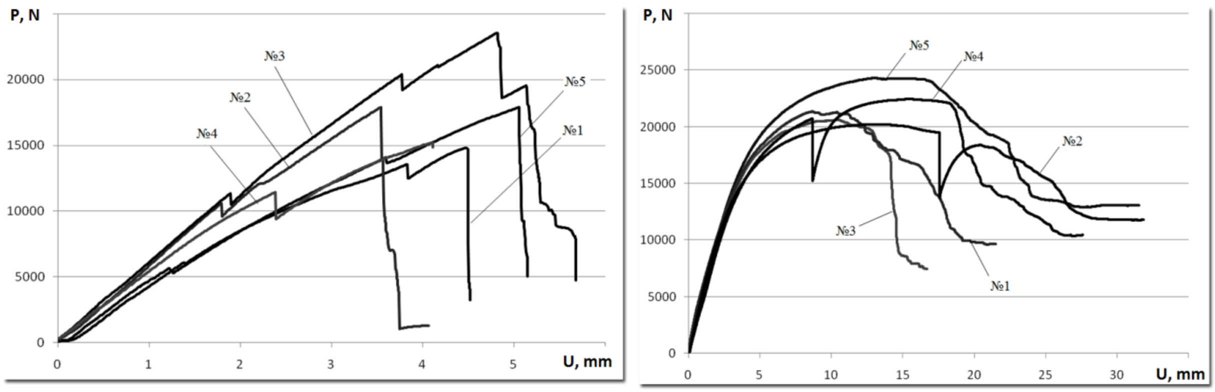
Figure 4. Axial (a) and shear (b) stresses in the samples of panel with cellular core under load of 1N, MPa.

The results of the numerical simulations were compared with the test data. Tests for tensile and shear properties of sandwich panels with *cellular* core were conducted on the universal electromechanical machine Instron 5882 using a specially developed fixture in the "Center of Experimental Mechanics" at Perm National Research Polytechnic University (figure 5) [8]. Tensile and shear stress-strain curves for tested specimens are given in figure 6.



a b

Figure 5. Tensile (a) and shearing (b) tests of sandwich panel samples with special fixture.



a b

Figure 6. Tensile (a) and shear (b) stress-strain curves for sandwich panels with cellular core.

Effective Young's modulus and shear modulus of the sandwich panels were calculated from the obtained stress-strain curves. According to the rule-of-mixtures effective elastic properties of cellular core can be computed from the test data. The results of simulations and tests are given in table 2. Good correlation between experimental data and calculated results was found.

Test method	**Effective elastic modulus of sandwich panel /cellular core, GPa**	
	Experimental data	**Numerical simulations**
Tensile	1,62 / 1,09	1,7 / 1,14
Shear	0,242 / 0,048	0,257 / 0,051

Table 2. Effective elastic modulus of sandwich panel and cellular core made of fiberglass

4. Conclusion

It is important to know mechanical properties of sound-absorbing acoustic sandwich panels (acoustic liners) and different types of fillers (cores). This work shows that effective mechanical properties can be very well determined by numerical techniques.

Computer models of sound-absorbing panels with different types of core were created. Calculations of the stress-strain state in the panels under various loading conditions and estimates of aggregates strength can be obtained by ANSYS software using these models. Effective elastic properties of fillers and sandwich panels calculated with the help of averaging strain and stress fields. The results of numerical simulations of mechanical behaviour of sandwich panels were compared with the test data, good correlation was found.

The created numerical models and results of this work will be used for new fundamental investigation dedicated to the development of experimental and theoretical principles of the mechanical analysis of self-diagnosable (smart-) materials based on optical fibers and piezoelectric elements. These elements embedded in sandwich panels will allow to control the mechanical behavior of constructions in real-time mode.

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