INFLUENCE OF DELAMINATION ON THE MECHANICAL PROPERTIES OF COMPOSITE SANDWICH-PANELS

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Abstract
Today sandwich panels made of fibrous polymer composite materials are widely used in aviation industry. Various types of core are used in these panels depending on their purpose - tubular, cellular or honeycomb. High-quality bonding of core and skins is one of the key factors for providing of overall stiffness and structural strength. This work presents a methodology based on the numerical simulation for assessment of the effects of defects in the form of delamination on the mechanical properties of composite sandwich panels. The three-dimensional parametric models of panels with tubular and honeycomb cores were created. Both solid and shell models were used. Simulation of delamination was performed by contact parameters changing in local areas of predetermined shape and dimensions. Such materials as carbon fiber reinforced plastic (CFRP) and fiberglass were examined. The numerical stress-strain analysis of panels under various loading condition was obtained with ANSYS Workbench software. The developed numerical models allow to study the effects of delamination defects on the stress and strain fields in multilayer composite sandwich panels according to the size and location of the defect.

1. Introduction

Today sandwich panels made of fibrous polymer composite materials are vital elements of many modern aircrafts and turbojet engines. Sandwich structures consist of a lightweight thick core and two thin strong skins bonded by thin adhesive films. These structures have high specific stiffness, sound and thermal insulating properties [1].

Various types of core are used in these panels depending on their purpose - tubular, cellular or honeycomb, arranged in one, two or even three layers (Fig. 1). High-quality bonding of core and skins is one of the key factors for providing of overall stiffness and structural strength. Often constructions with multilayer sandwich panels may work under the complex stress condition and the local areas of disbond between core and skins can considerably reduce bearing strength of the product. Also, defects in the form of delamination can be observed in multi-ply skins of sandwich panels.

The most researches that are devoted to mechanical behavior of sandwich panels describe the honeycomb core structures, for example [2-7]. A comprehensive review of the computational models on honeycomb sandwiches was given by Noor et al. [8], where numerous references were cited.

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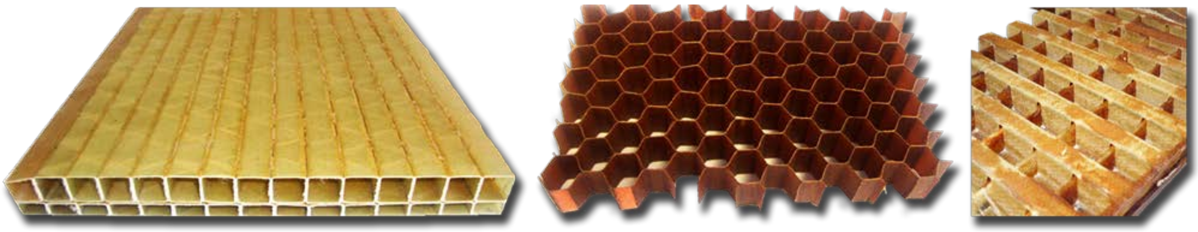

a) b) c)

Figure1. Types of core: tubular (a), honeycomb (b) and cellular (c).

Present work continues the previous study of the mechanical properties of composite sandwich panels with various core types [9-13]. The goal of this research is the development of methodology for analysis of effects of delamination on the mechanical properties of composite sandwich panels.

It may be noted that the created numerical models and the results of this work will be used for fundamental investigation devoted to the development of experimental and theoretical principles of the mechanical analysis of smart materials with embedded fiber Bragg grating (FBG) sensors for structural health monitoring (SHM) [14-16].

2. Structures and models of sandwich panels.

The numerical analysis of stress-strain state of sandwich panel under various conditions of loading was obtained with ANSYS Workbench software. For this simulation the 3D parametric models of sandwich panels corresponding to full-scale samples used for mechanical tests were created [9-11]. The describing of test technique and results can be found in [12, 13]. Initial mechanical properties and strength characteristics of the materials used in numerical studies were obtained in in-house tests.

The following simulation cases were examined: 1 – the longitudinal tension of sandwich panel with tubular core made of fiberglass, 2 – the longitudinal tension and 4-point bending of sandwich panel with carbon skins and fiberglass honeycomb core. Simulation of delamination between the core and skins was performed by contact parameters changing in local areas of predetermined shape and dimensions. Thus the areas in form of circle with radius of 10 mm, 15 mm and 30 mm were searched.

Fig. 2 shows the 3D models of panels with delamination area located in the center. For longitudinal tension models (Fig. 2, a, b) thanks to symmetry of the modelled specimens, simulations can be reduced by investigation of their halves only. Gripping fixtures, used for installing a sample in a testing machine, were also modelled in order to reproduce a character of load application in real experiments. The fixture system consisted of steel pads, a gasket, a seal and bolts.

The layouts of internal structure of sandwich panels are shown on Fig. 3. For example, the studied sandwich panel with tubular core consists of three-ply 90/0/90 and two-ply 90/0 laminate skins and tubes with 70/-70 laminate faces.

Fig.4 shows the FE meshes of sandwich panels for various simulation cases. Both solid and shell models were used for panel with honeycomb core to analyze the possible influence of different approaches of FEM technique on the results. Meshing was automatically implemented in ANSYS Workbench using tetrahedral Solid186 or Shell281 finite elements. The mesh density was considered optimal when the difference between the results of successive calculations with a refined mesh did not exceed 5 - 10%.

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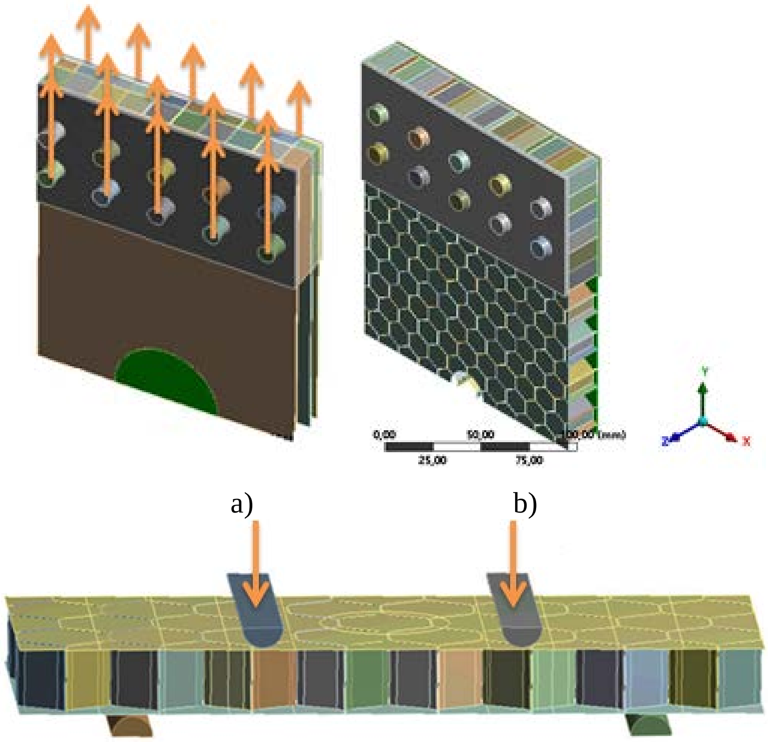
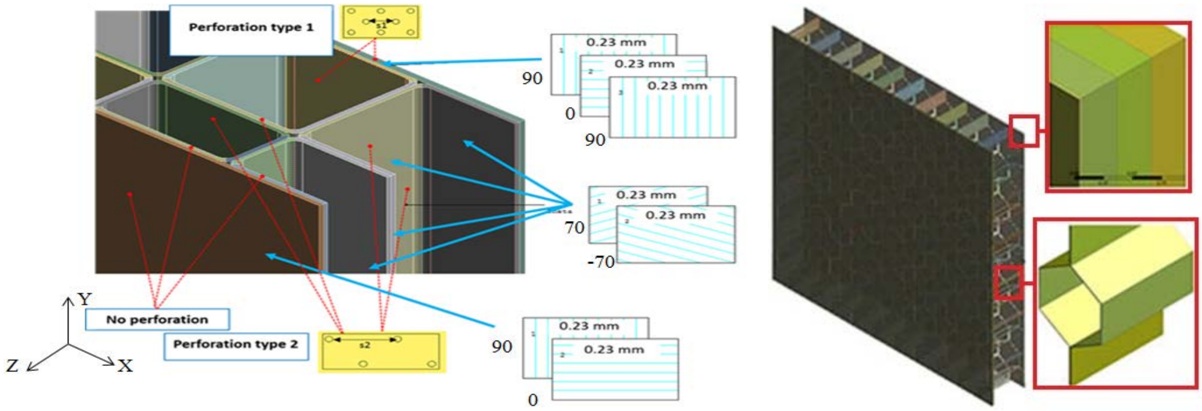


Figure 2. 3D models of sandwich panels with delamination area: longitudinal tension of sandwich panel with tubular core (a) and honeycomb core (b), 4-point bending of sandwich panel with honeycomb core (c).



a) b)

Figure 3. Layout of internal structure of sandwich panel: with tubular (a) and honeycomb (b) core

Some skins of panels which are used, for example, as acoustic liners in the nacelle of aircraft turbojet engines have perforation which occupies up to 10% of the entire area, and perforation holes diameter is correlated with the ply thickness. This factor should also be considered in assessing of performance of the sandwich panels.

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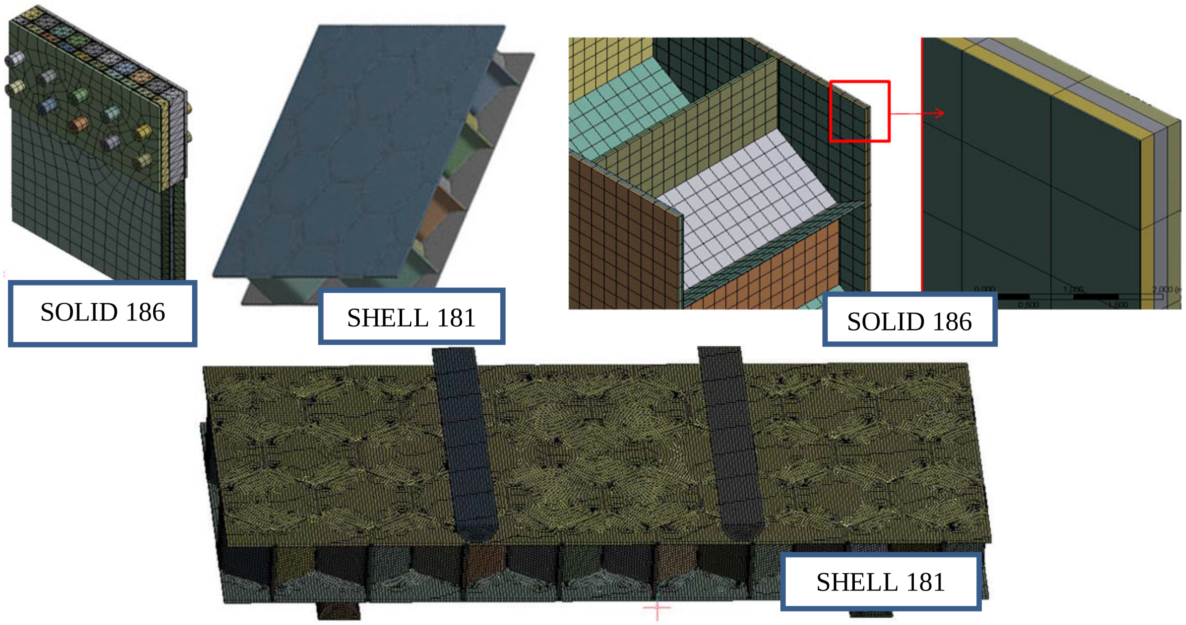

Figure 4. FE meshes of sandwich panels for various simulation cases.

The direct modelling of such structural elements is connected with computational difficulties due to a large number of small-sized curved areas (holes) that require a fine FE mesh. Thus it was necessary to obtain the effective properties of each perforated laminate. Various reinforcement schemes and two types of perforation, dense and sparse, were considered.

As perforation was periodic, the unit cell of laminates could be considered for assessment of their effective properties. The considered laminates were orthotropic, characterized by nine independent elastic constants: the Young's moduli E_X, E_Y, E_Z, Poisson's ratios ν_{XY}, ν_{YZ}, ν_{XZ}, and shear moduli G_{XY}, G_{YZ}, G_{XZ}. Three types of numerical experiments were implemented for each cell of the perforated laminates: tension along X and Y axes to determine the effective Young's moduli and Poisson's ratios, and pure shear in the XY plane to calculate the shear modulus. In each case the model was subjected to a kinematic loading condition of 1 mm displacement on the corresponding border.
The calculations of effective elastic and strength characteristics of perforated layered shells were obtained with ANSYS Mechanical software employing Shell281 finite elements (Fig. 5).

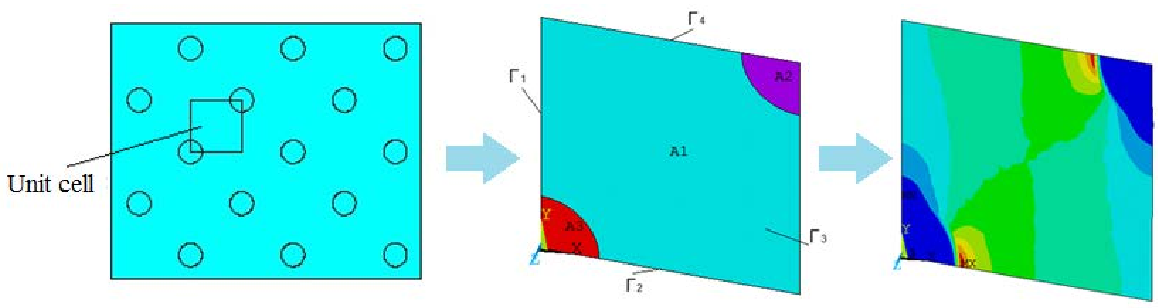

Figure 5. Approach for calculation of effective properties of the perforated laminates.

The homogenized constants of the perforated laminates – the elastic moduli and Poisson's coefficient – were obtained with the following equations:

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$$E_x^* = \frac{\langle \sigma_x \rangle}{\varepsilon_x^*}, \quad E_y^* = \frac{\langle \sigma_y \rangle}{\varepsilon_y^*}, \quad E_z^* = \frac{\langle \sigma_z \rangle}{\varepsilon_z^*}$$
$$G_{xy}^* = \frac{\langle \tau_{xy} \rangle}{\gamma_{xy}^*}, \quad G_{yz}^* = \frac{\langle \tau_{yz} \rangle}{\gamma_{yz}^*}, \quad G_{xz}^* = \frac{\langle \tau_{xz} \rangle}{\gamma_{xz}^*} \qquad (1)$$
$$\nu_{xy}^* = \left|\frac{\varepsilon_y^*}{\varepsilon_x^*}\right|, \quad \nu_{yz}^* = \left|\frac{\varepsilon_z^*}{\varepsilon_y^*}\right|, \quad \nu_{xz}^* = \left|\frac{\varepsilon_z^*}{\varepsilon_x^*}\right|$$

where strains ε_x^*, ε_y^*, ε_z^* and γ_{ij}^* were predetermined in the numerical experiments.

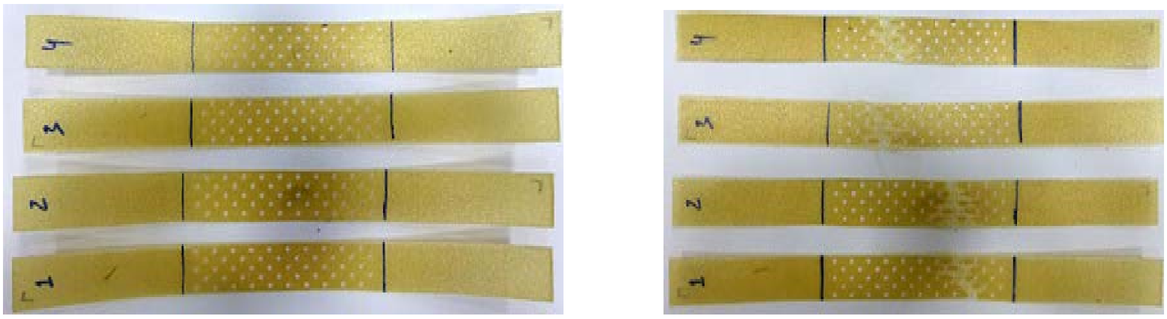
The mean stress values were calculated using the following relation:

$$\langle \sigma_i \rangle = \frac{\sum_{i=1}^{n} \sigma_i V_i}{V_M} \qquad (2)$$

where n is number of finite elements in the unit cell, σ_i is stress in the i^{th} finite element, V_i is its volume, V_M is the representative volume.

It was shown that the perforation leads to decrease of material stiffness up to 30%, and strength – up to 40-60%.

Verification of the proposed numerical algorithm for calculation of effective properties of the perforated laminates and obtained results were carried out with the help of tensile tests of special specimens of 2-plies laminates (Fig. 6) according to ASTM D 882 [17].



a) b)

Figure 6. Perforated specimens of 2-plies laminate before (a) and after (b) tensile testing.

Static tests were conducted on Zwick/Roell Pro Line Z100 testing machine with contact-type long-travel extensometer. Tensile stress-strain curves for tested specimens are given in Fig. 7. The results of numerical simulations were compared with the test data. Good correlation was found.

3. Numerical modelling of mechanical behaviour of sandwich panels.

The numerical studies included development of finite-elements models of the considered sandwich panel specimens under tensile loading and 4-point bending. The problems were solved in a general statement for an anisotropic elastic body. A mathematical formulation was given in [10, 11].

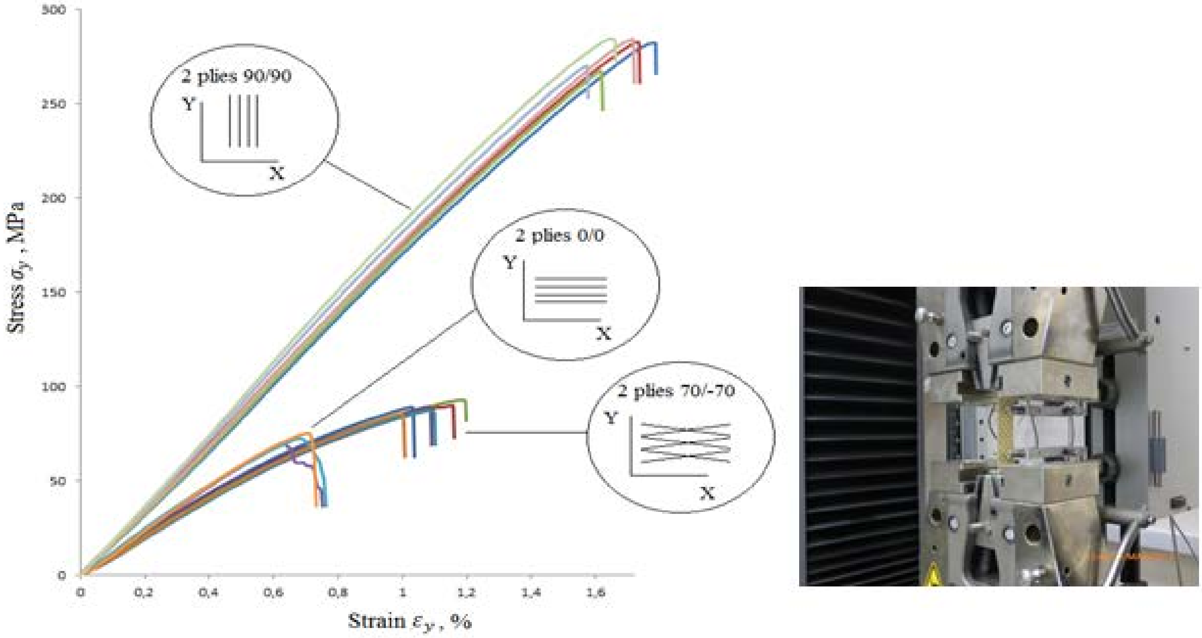


Figure7. Tensile stress-strain curves for perforated specimens with various reinforcement schemes and testing fixture with contact-type extensometer.

As a result of the numerical simulation, stress and strain fields were obtained for each structure component of panels. For example, Fig. 8 shows the calculated total displacements in the sample of panel with delamination defect under the load of 100 kN and fields of stress in skins and tubular core. Similarly the stress analysis for sandwich panel with honeycomb core can be realized (Fig. 9).

The effective approach for research of mechanical behavior is the analysis of stress distribution along the different paths. Thus, Fig. 10 shows various paths on the top three-ply laminate skin of sandwich panel under 4-point bending load. A comparison of obtained solution data for various delamination defects with the results for a defect-free panel allows to estimate the impact of defect on the static strength and stress-strain state of panel (Fig. 11).

The results analysis shows that delamination of the core from facesheet invokes the stress redistribution near the defect area. The several sizes of delamination were considered and it was shown that in general there was no effect on static strength of sandwich panel with tubular and honeycomb core under tensile loading condition. The local changes of stress components are more noticeably for sandwich panels with honeycomb core due to specific type of contact boundary. Nevertheless the difference between stress values for defect-free and defective panel does not exceed 5%.

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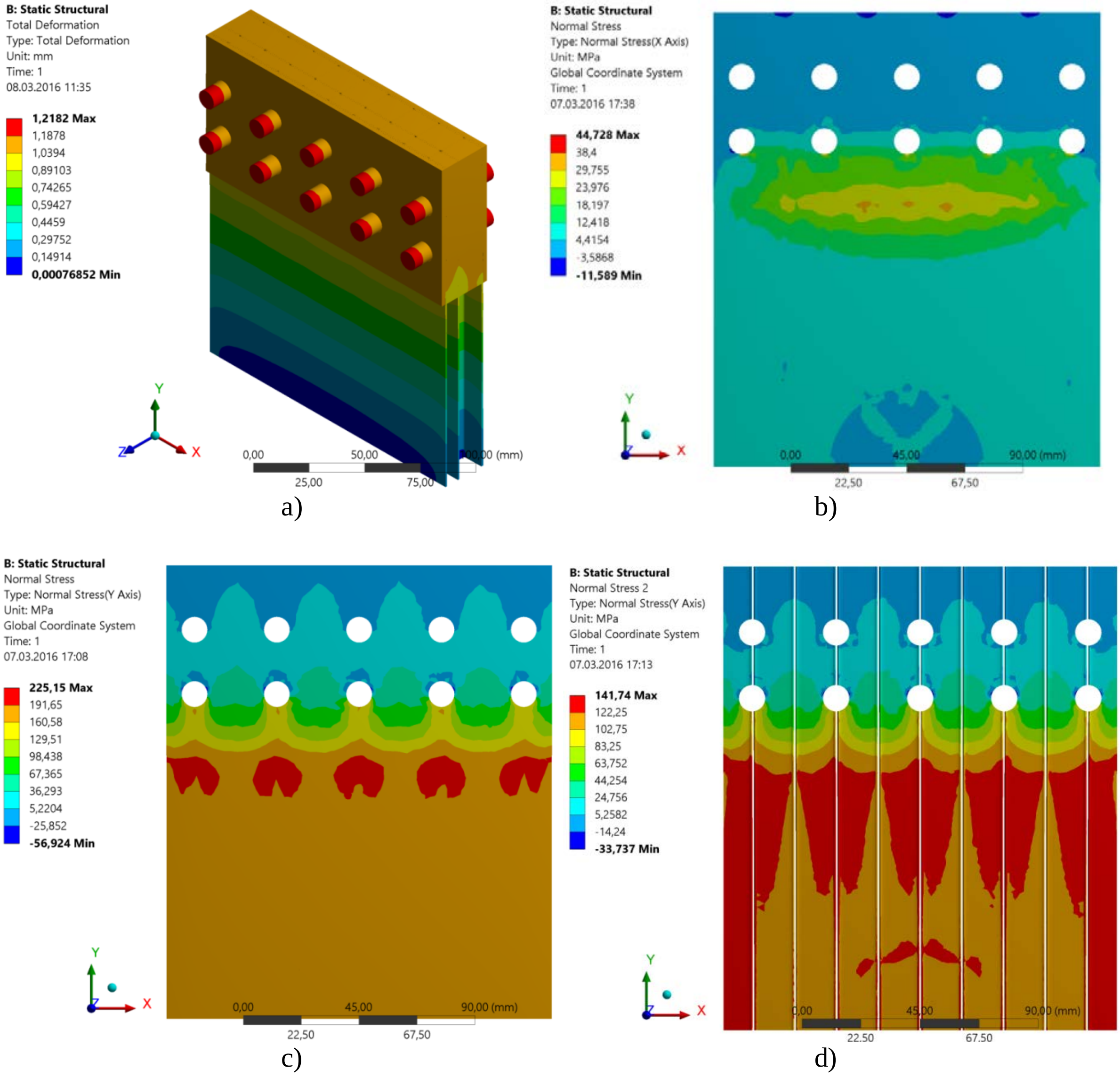

Figure 8. Calculated total displacements [mm] (a) and fields of stress [MPa] in skins (b, c) and tubular core (d) of sandwich panel with delamination defect.

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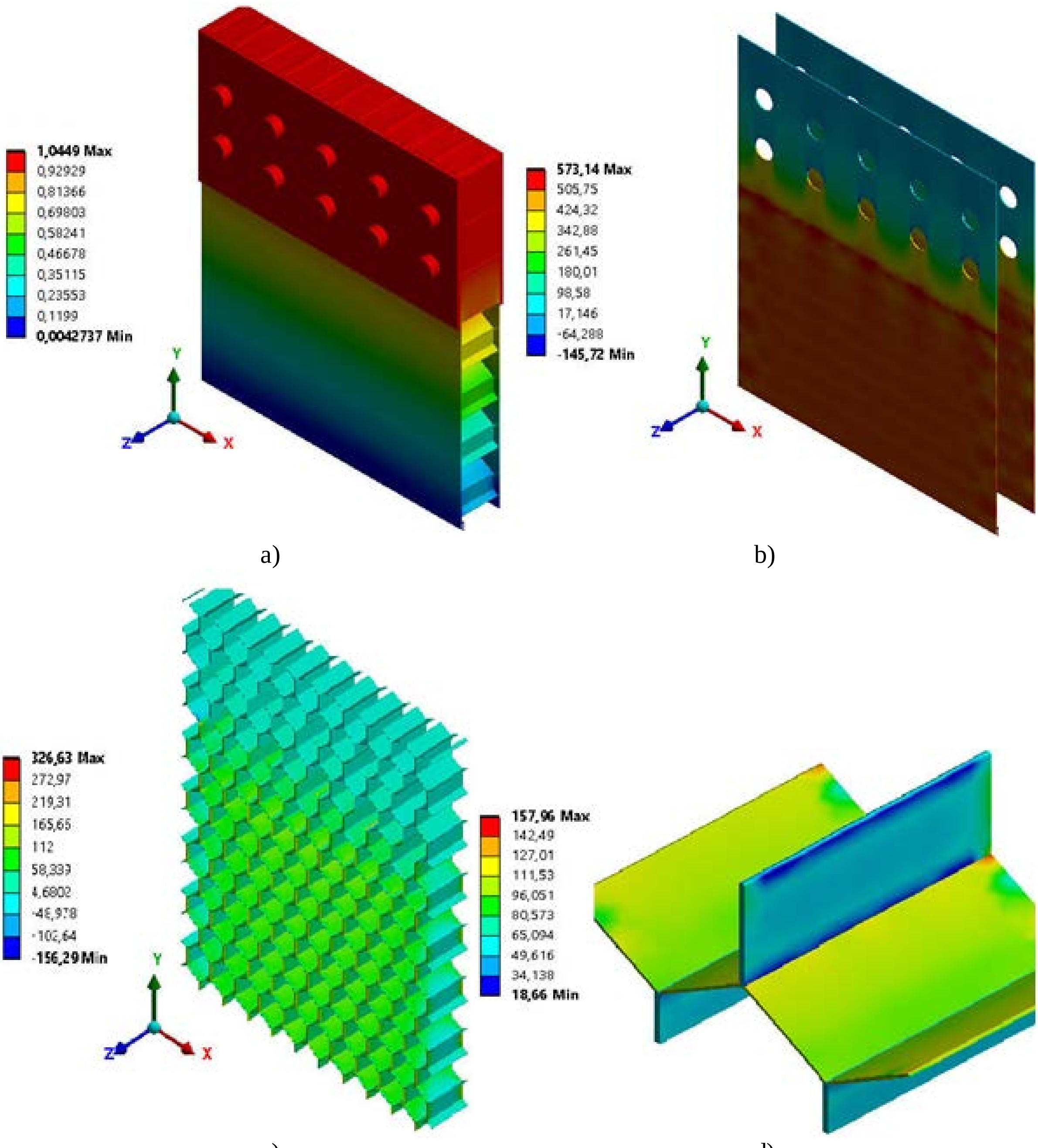

Figure 9. Calculated total displacements [mm] (a) and fields of stress [MPa] in skins (b) and honeycomb core (c, d) of sandwich panel with delamination defect.

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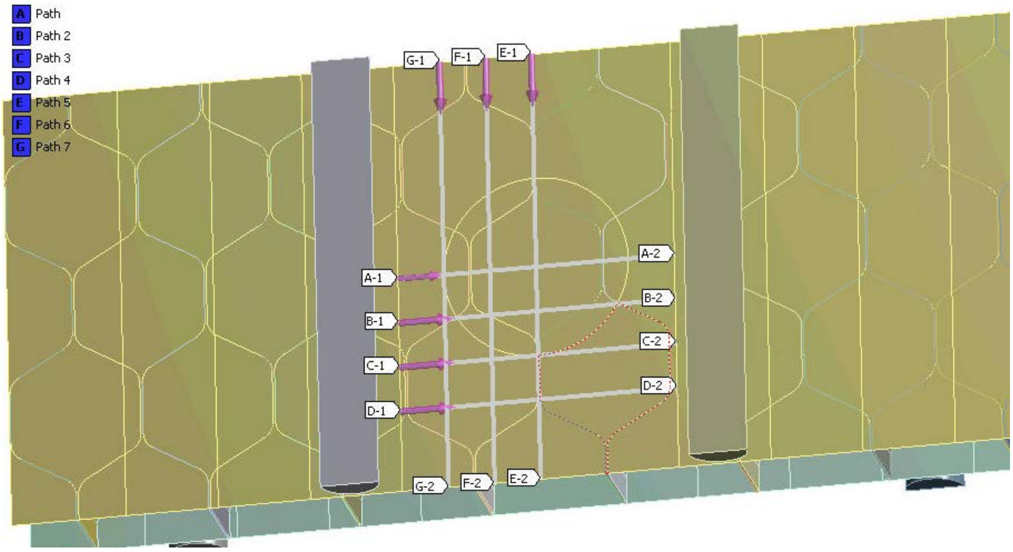
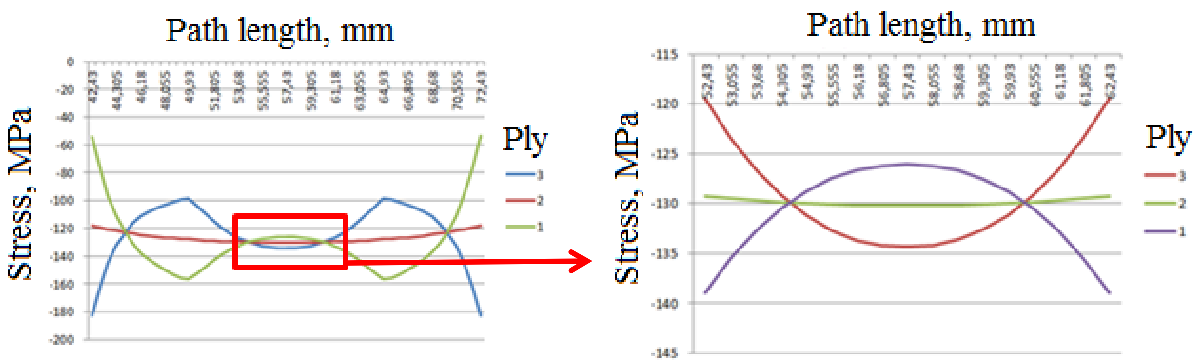
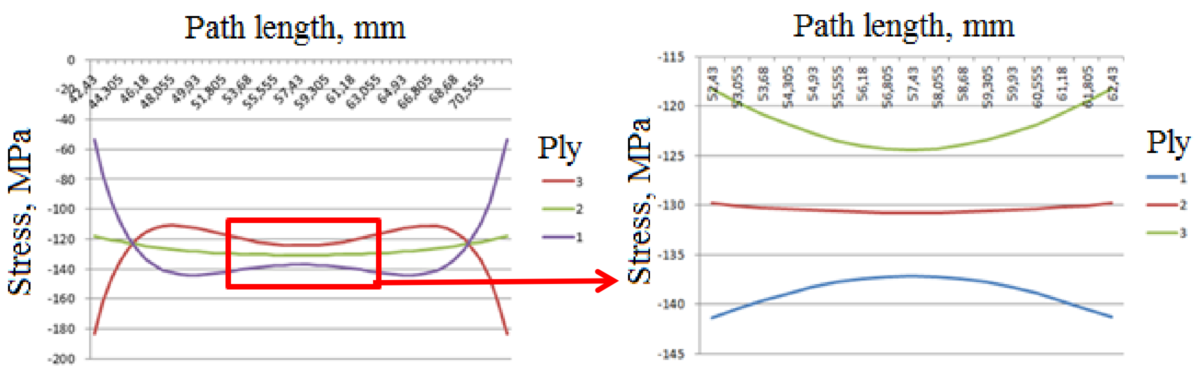


Figure 10. Paths for stress distribution analysis on the top three-ply laminate skin of sandwich panel under 4-point bending load.



a)



b)

Figure 11. Bending stress distribution along the A1-A2 path: a) – defect-free panel, b) – panel with delamination defect (radius 10 mm).

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4. Conclusion

This work is devoted to development of a methodology based on the numerical simulation for assessment of the effects of defects in the form of delamination on the mechanical properties of composite sandwich panels. Various types of core are used in these panels depending on their purpose - tubular, cellular or honeycomb. Several studies have shown that delamination of the core from facesheet is a typical failure mode for sandwich panels. In addition, some skins have perforation which occupies up to 10% of the entire area, and perforation holes diameter is correlated with the ply thickness. This factor should also be considered in assessing of performance of the sandwich panels.

The three-dimensional parametric models of panels with tubular and honeycomb cores were created. Both solid and shell FE models were used. The numerical stress-strain analysis of panels under various loading condition was obtained with ANSYS Workbench software. The following simulation cases were examined: 1 – the longitudinal tension of sandwich panel with tubular core made of fiberglass, 2 – the longitudinal tension and 4-point bending of sandwich panel with carbon skins and fiberglass honeycomb core. Simulation of delamination was performed by contact parameters changing in local areas of predetermined shape and dimensions. A comparison of obtained solution data for various delamination defects with the results for a defect-free panel allows to estimate the impact of defect on the static strength and stress-strain state of panel.

The prior analysis has shown that in general there was no effect on static strength of sandwich panel with tubular and honeycomb core under tensile loading condition. The local changes of stress components depending on size of delamination are more noticeably for sandwich panels with honeycomb core due to specific type of contact boundary. Nevertheless the difference between stress values for defect-free and defective panel does not exceed 5%. However it is significant to note that the problem of delamination in composite sandwich panels is extremely important for fatigue life prediction for such structures. The solution of this problem will be the aim of the further researches.

The analysis of effect of perforation on mechanical properties of fiberglass sheets was also performed in this work. It was shown that the perforation leads to decrease of material stiffness up to 30%, and strength – up to 40-60%. Verification of the proposed numerical algorithm and obtained results was carried out with the help of tensile tests of special specimens according to ASTM D 882.

It can be concluded that the developed numerical models allow to study the effects of delamination defects on the stress and strain fields in multilayer composite sandwich panels according to the size and location of the defect. The results of this work can be used for structural health monitoring (SHM) of these structures with embedded fiber Bragg grating (FBG) sensors. Thus the numerically obtained stress distribution near the possible defect can help to determine the dimension of effective sensitive zone for embedding FBG sensors.

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