Experimental Validation of Numerical Model of Composite Panel for Aerospace Structural Applications

Mucha W.*, Kuś W.*, Viana J. C.** , Nunes J. P.**

*Department of Computational Mechanics and Engineering, Silesian University of Technology, Poland
**Department of Polymer Engineering, IPC - Institute for polymers and composites, University of Minho, Portugal

Abstract

Composite panels are widely used in aerospace structural applications (e.g., fuselage, wings). A typical hat-stiffened panel was manufactured using the vacuum infusion process. The applied material is carbon/epoxy 10-layer laminate. The global properties of the laminate were computed from the mechanical properties of a single ply. Finite element model of the panel was created and validated experimentally by measuring bending stiffness of the panel in different points.

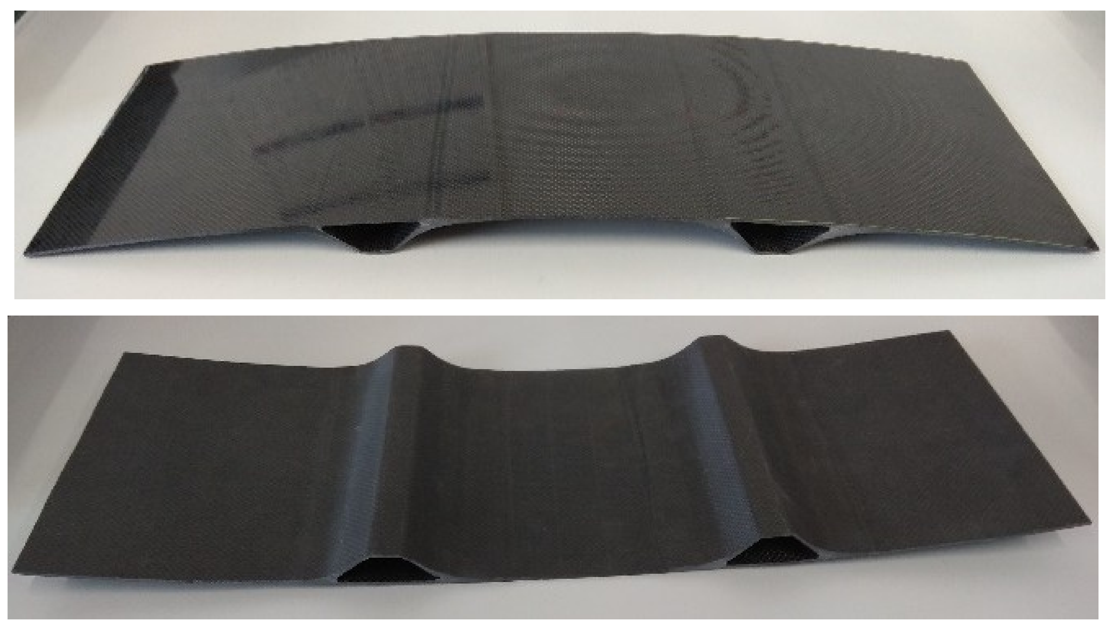

Fig. 1. Considered aerostructure

Introduction

In aerospace structural applications weight-efficiency is one of the most important criteria. It is understood as high stiffness and minimal weight. Composite structures provide large weight savings compared to metal structures, while remaining with relatively high stiffness.

In the following paper a hat stiffened panel, a typical structure for aerospace applications, is considered. The panel is made of epoxy composite reinforced by woven carbon fiber and is presented in figure 1.

The prototype panel was manufactured using vacuum infusion proces (figure 2). This technique utilizes vacuum pressure to enforce the resin flow into the laminate. Plies of carbon fiber were laid dry and sealed (using a bag) on the mold before the vacuum was applied to suck the resin via installed tubing. The overall dimensions of the panel are 597 x 204 x 29 mm.

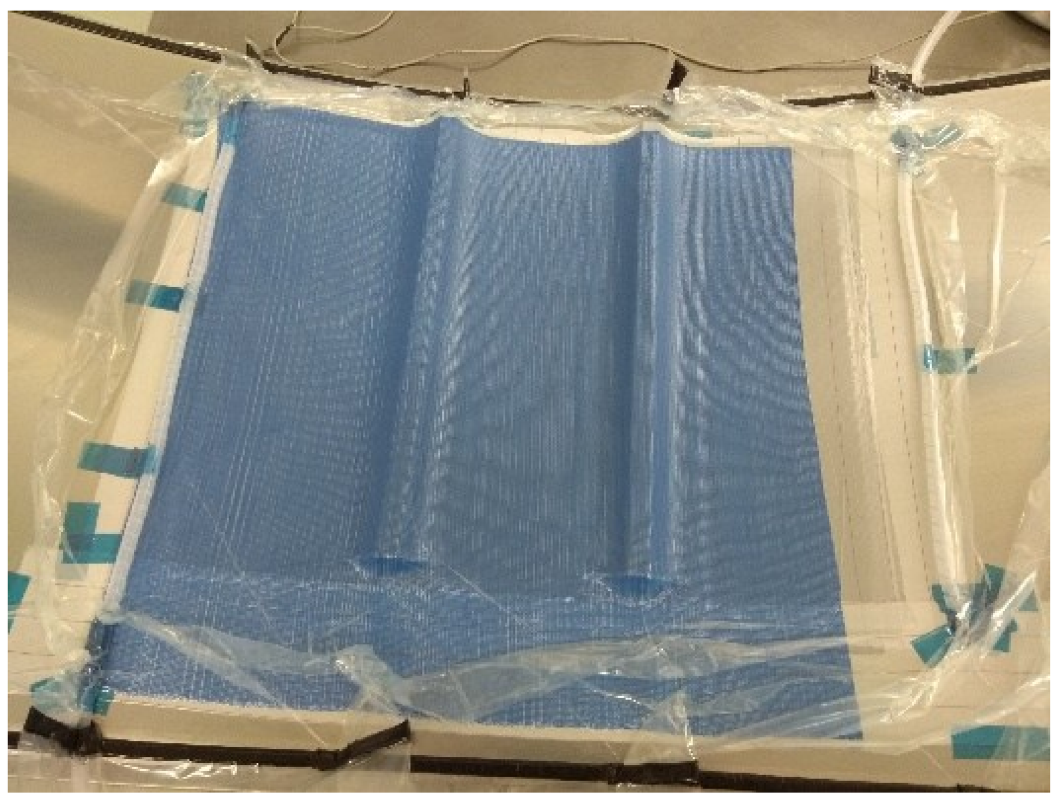

Fig. 2. Manufacturing of the panel – vacuum infusion process

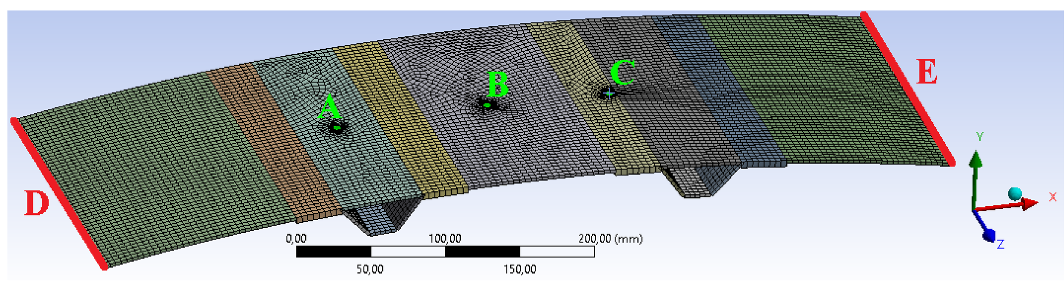

Fig. 3. FE model of the panel and boundary conditions

Numerical model

FE surface model was created using ANSYS Workbench with module ACP. The mesh and boundary conditions are presented in figure 3. **A** (middle of the hat reinforcement), **B** (middle of the panel) and **C** (side of the reinforcement rib) are 10 mm diameter surfaces where load along axis -Y is singly applied and corresponding displacement is measured. On edge **D** displacements along axes X and Y are fixed. On edge **E** only displacements along axis Y is fixed. Displacements along axis Z is fixed on the surface where load is currently applied. The mesh consists of 10840 quadratic-order elements and 32775 nodes.

The FE model was divided into two parts: basis and reinforcement (figure 4). Each of them consists of a 10-layer carbon woven / epoxy laminate with different direction of fibers. Thickness of a single ply is 0.23 mm, therefore the thickness of the panel is 2.3 mm (4 faces common for basis and reinforcement are 4.6 mm thick). Experimentally measured mechanical properties of a single ply and computed properties of the laminate are presented in Table 1.

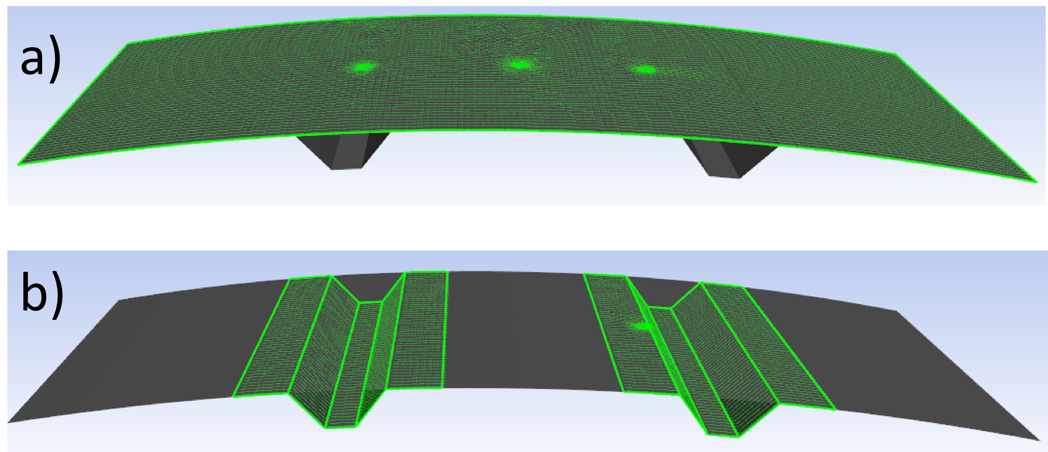

Fig. 4. Model division: a) basis, b) reinforcement

Table 1 Orthotropic material properties

Constant	Single ply	Basis	Reinforcement
E_x [MPa]	64700	50600	**64700**
E_y [MPa]	64700	50600	**64700**
E_z [MPa]	7171	7171	**7171**
ν_{xy} []	0.04	0.249	**0.04**
ν_{yz} []	0.34	0.266	**0.34**
ν_{xz} []	0.34	0.266	**0.34**
G_{xy} [MPa]	4000	14800	**4000**
G_{yz} [MPa]	2662	2662	**2662**
G_{xz} [MPa]	2662	2662	**2662**

Numerical results

Figure 5 presents displacements along axis Y when unit load (1 N) is applied to point A. Corresponding displacement at point A (for load applied to the same point) was 0.1541 mm, which gives bending stiffness equal to 6.49 N/mm. Computed bending stiffnesses at points B and C are 4.27 N/mm and 5.79 N/mm, respectively.

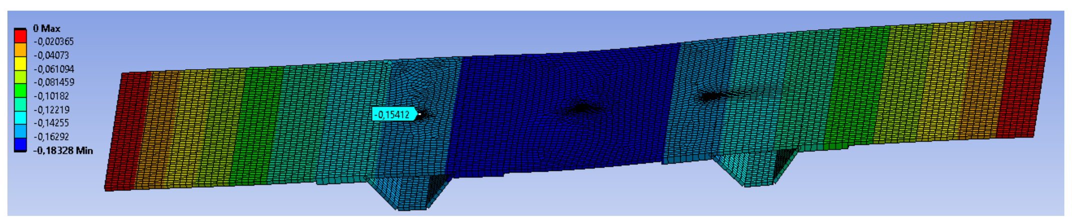

Fig. 5. Y-displacements [mm] when unit load is applied to point **A**

Experimental verification

Experimental verification and validation of the obtained numerical results was performed using universal testing machine MTS Insight 10 equipped with a 500 N load cell. (Fig. 6a). The test velocity was 0.5 mm/min. Fig. 6b presents the results of the performed experiments – the obtained force-displacement curves. Bending stiffnesses obtained from linear regressions of the curves are: 6.48 N/mm, 4.32 N/mm, and 5.79 N/mm, when loading at points A, B and C, respectively. The relative error between obtained numerical and experimental results is: 0.14%, 1.24% and 0.15%, respectively.

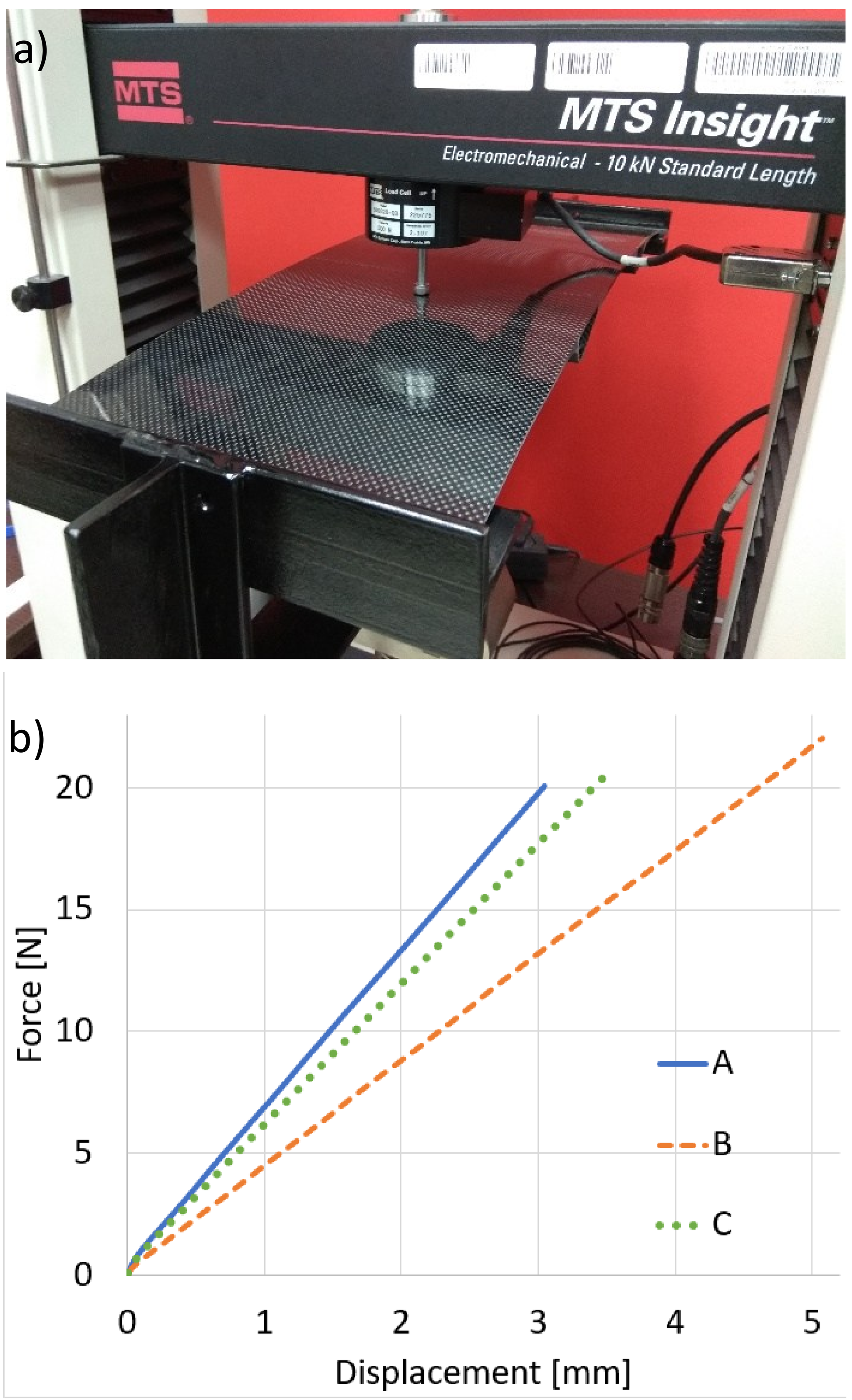

Fig. 6. Testing experiment: a) panel mounted in universal testing machine, b) obtained force-displacement results

Conclusions

As one can see in figure 6, the force-displacement plots are nearly ideally linear. Experiment confirmed that the FE model is very accurate, as evidenced by low relative error 0-2%.

Authors, in their future work, plan to mount strain gauges to the composite panel and develop methods for real-time operational load monitoring utilizing artificial intelligence techniques. FE model presented in the following paper will enable authors to create algorithms for this purpose.

Contact

Waldemar Mucha, PhD. Eng.
Department of Computational Mechanics and Engineering
Faculty of Mechanical Engineering
Silesian University of Technology
Email: waldemar.mucha@polsl.pl
Website: http://imio.polsl.pl/WMucha.aspx
Phone: +48 32 237-12-04

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