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EXPERIMENTAL VALIDATION OF NUMERICAL MODEL OF COMPOSITE PANEL FOR AEROSPACE STRUCTURAL APPLICATIONS

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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.*

Keywords: Hat-stiffened panel, Finite element method, Laminate, Bending stiffness.

1. Introduction

In aerospace structural applications weight-efficiency is one of the most important criteria. It is understood as high stiffness and minimal weight (Kim et al., 2010). Composite structures provide large weight savings compared to metal structures, while remaining with relatively high stiffness (Zhou et al., 2019). Typical aerospace lightweight structures are sandwich panels (with foam, honeycomb, web or truss core – Arunkumar et al., 2016) or stiffened composite panels (e. g. with blade ribs, T-bar ribs or hat-ribs – Pravallika and Yugender, 2016; Zalewski and Bednarcyk, 2010). In the following paper a hat stiffened panel is taken into consideration. The panel is made of epoxy composite reinforced by woven carbon fiber.

a) b)

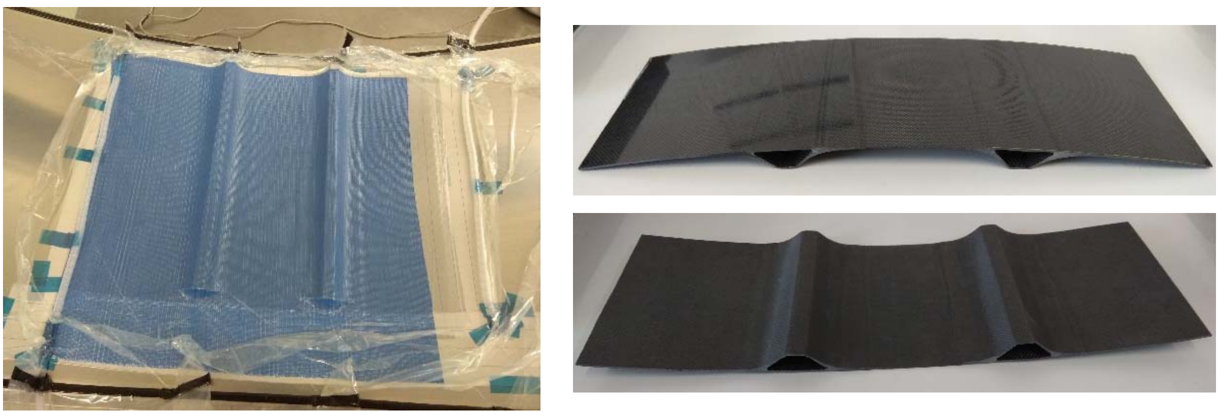

Fig. 1: Hat stiffened composite panel: a) vacuum infusion process; b) final result.

A prototype panel was manufactured using vacuum infusion process. This technique utilizes vacuum pressure to enforce the resin flow into the laminate. Plies of carbon fiber were laid dry and sealed (using

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a bag) on the mold before the vacuum was applied to suck the resin via installed tubing. Fig. 1 presents a photograph from the production of the panel and the final result. The overall dimensions of the panel are 597 x 204 x 29 mm.

A finite element (FE) model of the panel was created (Ochoa and Reddy, 1992) using ANSYS Workbench software and is presented in section 2. The model was validated experimentally by comparing bending stiffness measured numerically and experimentally in different points (section 3). The conclusion is presented in section 4.

2. Numerical model

The FE model was divided into two parts (Fig. 2): basis and reinforcement. Each of them consists of a 10-layer carbon woven / epoxy laminate with direction of fibers presented in Tab. 1 (assuming even symmetry). 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).

a) b)

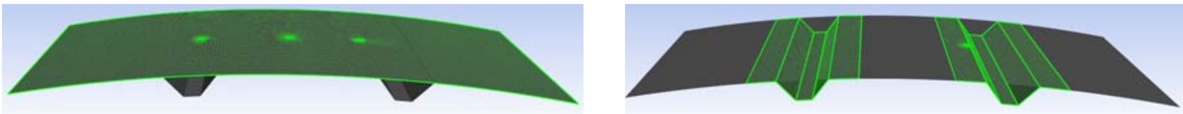

Fig. 2: Model division: a) basis; b) reinforcement.

Tab. 1: Ply orientation of the laminate in [°].

Ply number	Basis	Reinforcement
1	0 / 90	0 / 90
2	-45 / 45	0 / 90
3	0 / 90	0 / 90
4	-45 / 45	0 / 90
5	0 / 90	0 / 90

Experimentally measured mechanical properties of a single ply and computed properties (using MSC Patran) of the laminate are presented in Tab. 2. The materials are orthotropic, being characterized by 9 constants: 3 Young's modules E_i along axis i, 3 shear modules G_{ij} in direction j on the plane whose normal is in direction i, and 3 Poisson's ratios ν_{ij} that correspond to a contraction in direction j when an extension is applied in direction i. z is here the axis perpendicular to the plane of the ply/laminate.

Tab. 2: Mechanical properties of single ply and laminate.

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

FE surface model was created using ANSYS Workbench with module ACP. The mesh and boundary conditions are presented in Fig. 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.

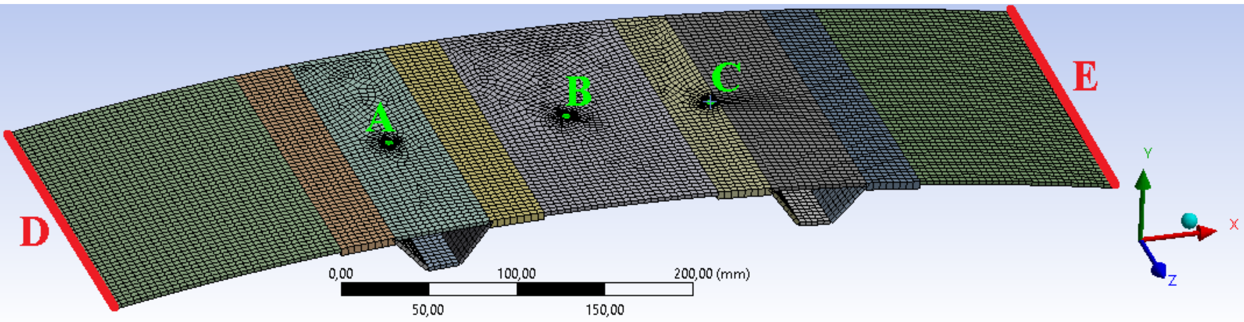

Fig. 3: Mesh and boundary conditions of FE model.

Fig. 4 presents displacement along axis *Y* when unit load (1 N) is applied to point **A**. Corresponding displacement at point **A** was 0.1541 mm, which gives bending stiffness equal to 6.48 N/mm. Computed bending stiffnesses at points **B** and **C** are presented in section 3 with comparison to values measured experimentally.

a)
b)
c)

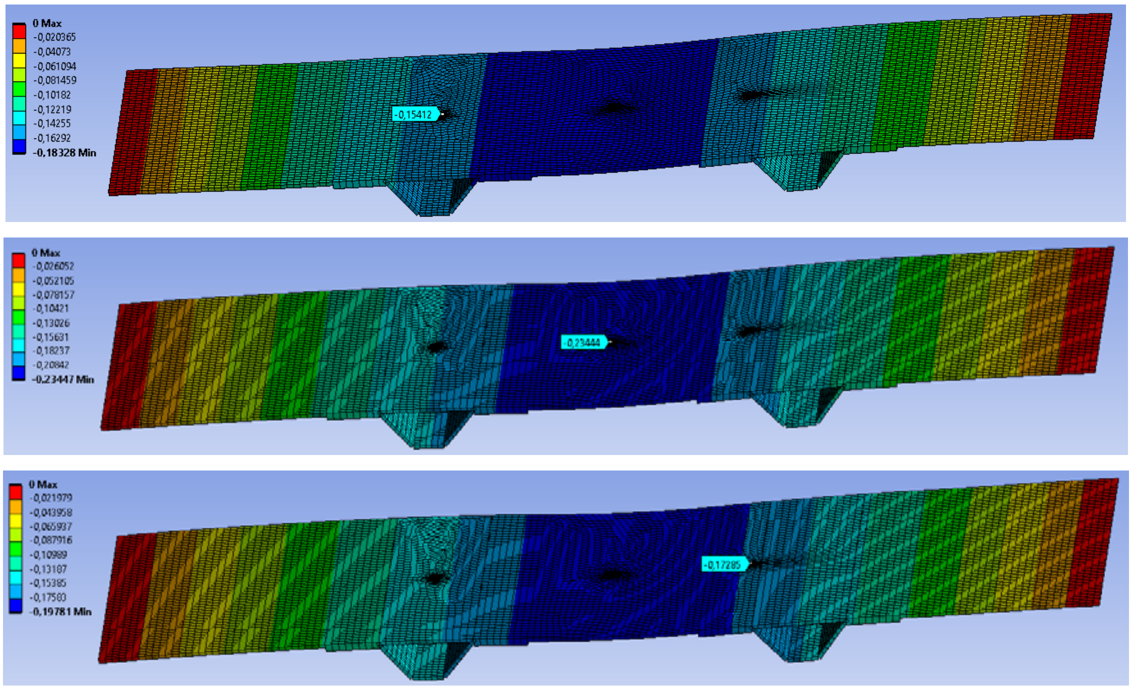

Fig. 4: Map of displacements [mm] along axis Y *when unit load is applied to point: a)* ***A****; b)* ***B****; c)* ***C****.*

3. Experimental validation

Experimental verification and validation of the obtained numerical results was performed using a universal testing machine MTS Insight 10 equipped with a 500 N load cell. (Fig. 5a). The composite panel was lied down on a specially designed steel frame of high stiffness to mimic the boundary conditions applied in FE analysis. The test velocity was 0.5 mm/min. Fig. 5b presents the results of the performed experiments – the obtained force-displacement curves. Bending stiffnesses obtained from linear regressions of the curves are compared with the stiffnesses computed numerically in Tab. 3.

4. Conclusion

As one can see in Fig. 5, 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 % (Tab. 3).

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.

a) b)

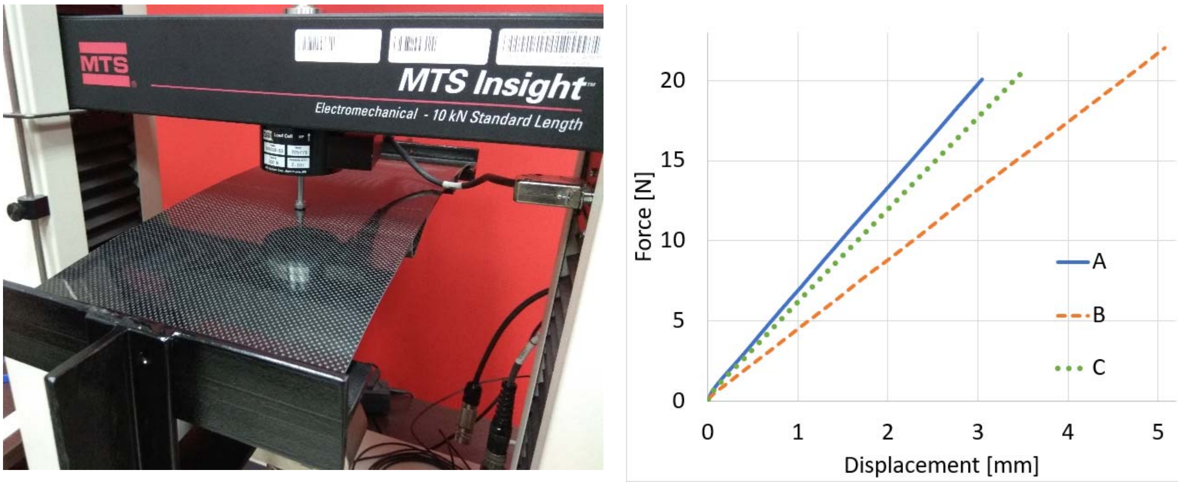

Fig. 5: Testing experiment: a) panel in universal testing machine photograph; b) obtained force-displacement results.

Tab. 3: Bending stiffnesses obtained numerically and experimentally.

Load point	Stiffness from FE model [N/mm]	Stiffness from experiment [N/mm]	Relative error of FE model [%]
A	6.4885	6.4794	0.14
B	4.2655	4.3189	1.24
C	5.7854	5.7941	0.15

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