Mechanical behavior of thermoplastic rib under loading representing real structure conditions

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Abstract: Paper deals with experimental verification of mechanical behavior and strain analysis of an airframe structural part manufactured from thermoplastic composite with tailoring blanks. Investigated structural part is represented by a rib which is embedded into the door structure of the large airliner. The prevailing load mode of the rib is shear. The test rig design comply with real structure boundary conditions. Non contactless strain measurements are compared with numerical simulations. The good match of measurements with numerical simulations was achieved. The results will be applied for the new design of the rib considering maximum weight and costs with saving.

Keywords: Composite, thermoplastic, tailoring blank, contactless measurement, strain analysis.

1 Introduction

The existing composite airframe structures are almost explicitly made out of thermosets. Thermoplastic materials used for high-performance composite structures bring several advantages both in design and manufacturing. The requested performance of structural parts can be achieved using stacking of tailored blanks with combination of thermoforming process. The paper is focused on the first industrial application of composite tailored blanks in the Czech Aerospace industry. The new technology was applied to the rib used in the fuselage door structure.

2 Test specimen and methodology

The AIMS05-09-002 carbon fiber fabric with satin pattern and PPS thermoplastic resin was used for the rib manufacturing. Thickness of the rib differs depending on the layout of fabrics. Nominal thickness of the fabric is 0.31 mm. Three different lay outs were used: a) 18 layers (t = 5,58 mm) $[0/(45/0)_4/0/(45/0)_3/0]$, b) 16 layers (t = 4,96 mm) $[(0/45)_4/45/(0/45)_3/0]$ and c) 11 layers (t = 3,41 m) [0/45/0/45/0/45/0/45/0/45/0]. The rib is shown in Figure 1. The test boundary loading conditions and the test principle were derived from the real part loading transfer in the door airframe structure. The main load is a moment came up from the force applied in the door lock and the stop fitting part. The rib is connected into the internal door frame using bolts. Stiffness and deformation of the circumferential door frame was neglected. The skin influence was taking into account for the test arrangement. The scheme of the designed test jig is shown in Figure 2. The attachment allows horizontal movement of the rib during loading through a special support trolley. The rib was loaded up to failure using MTS uniaxial hydraulic facility with capacity of 1 MN. The quasi static loading was applied. Deformation was measured using contactless digital image correlation system Q-400. Test arrangement is shown in Figure 3.

Fig. 1: Thermoplastic composite rib with tailored blanks.

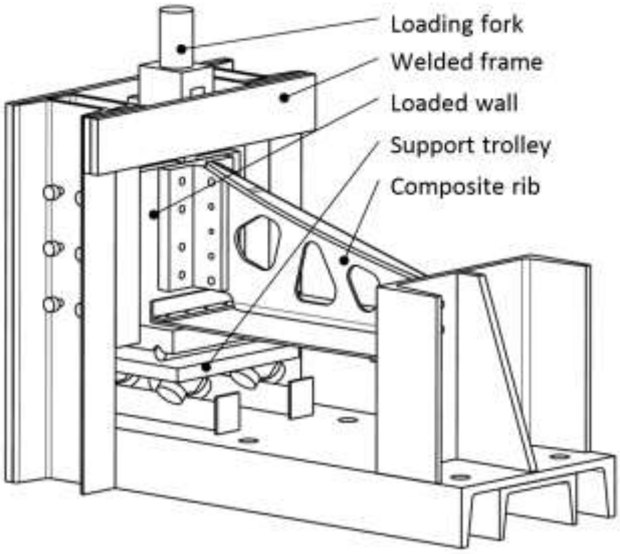

Fig. 2: Scheme of the test jig.

Fig. 3: Test arrangement with cameras of Q-400 image correlation system (left) and results image (right).

3 Results

The load-displacement dependence and relative deformations in three different axes were measured. Example of the deformation measured using Q-400 digital image correlation system in horizontal direction at 36 kN is shown in Figure 4. The relative shear deformation in the bottom section of the web along the x (horizontally) direction defined by experiment and numerical analysis is shown in Figure 5. Load vs. displacement curve is shown in Figure 6. The initial nonlinearity in the force vs. deformation curve is probably caused by assembly clearances. Then the linear loading curve up to 90 kN was measured. The second nonlinearity occurred due to stiffness changes and bearing strength when the loading force was approaching to failure.

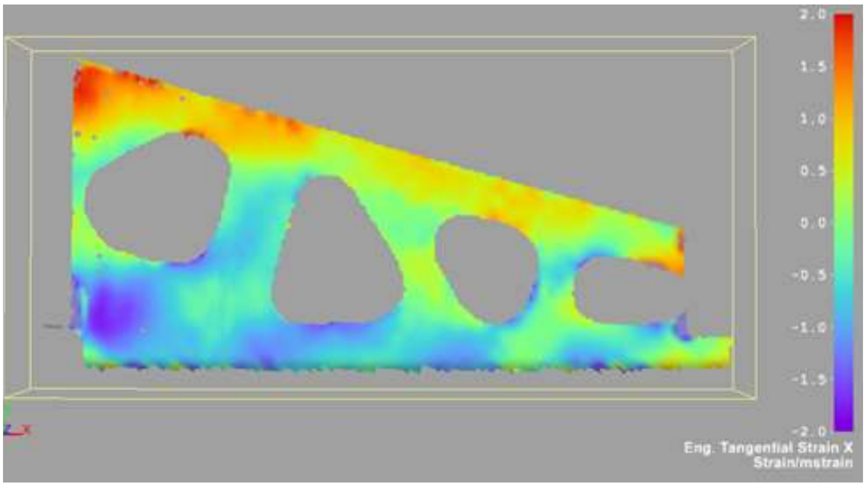

Fig. 4: Relative deformation in horizontal direction.

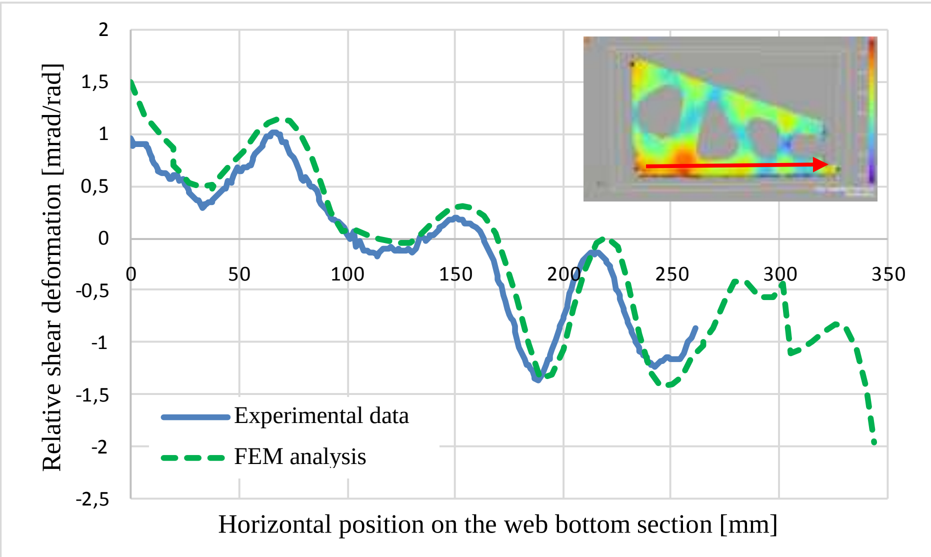

Fig. 5: Shear deformation in the web – comparison of experimental and FEM analyses.

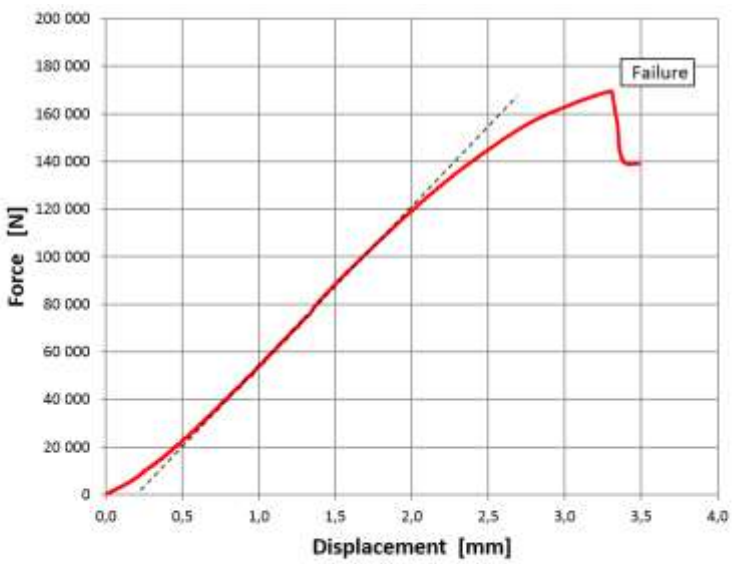

Fig. 6: Load vs. displacement curve.

The maximum force of 170 kN was achieved. The failure initiated in the end bolts fastening the rib to the surrounding structure. The failure initiated in good agreement with the prediction. Both experimentally measurements and numerical analysis confirm highest deformation in the failure area. Overview of the rib after failure is shown in Figure 7 (left) together with detailed view of damaged holes for bolts (right).

Critical areas in light of failure initiation are bolt holes located at the longer vertical part (web) of the rib. The holes placed in the upper web part are loaded in the direction out of the rib. The forces in upper part of the web invoke tensile bearing stresses in holes. The bottom holes near the skin are loaded by forces which are directed inside of the rib. These forces invoke compressive bearing stresses. Failure initiated from holes placed in the upper web part owing to lower capacity of joint in the tensile out of the rib direction.

Experimental strength of the rib was achieved multiply higher then it was required although the numerical optimization of the rib were carried out before the test. Strength optimization of the rib is the next work objective.

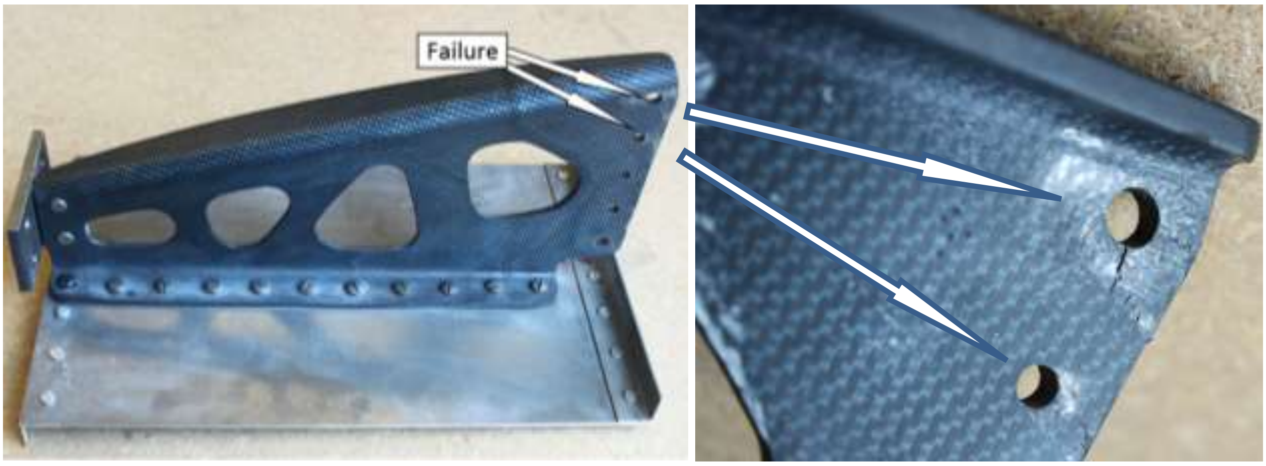

Fig. 7: The rib after failure.

4 Conclusion

The paper discusses experimental demonstration of mechanical behavior of the thermoplastic rib made of tailored blanks. The shear and deformation characteristics was evaluated and the good conformity with numerical predictions was achieved. The achieved strength of the rib was multiple higher then requirement. This shows evidence of the better utilization possibility of tailoring blank and the strength characteristics of the material. Therefore the next work will be focused on the strength optimization with the aim of significant weight saving.

Acknowledgement

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