The Electrobus Skeleton Parts – Experimental and Numerical Testing

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Abstract: The paper describes the experimental tests and numerical simulations of important parts of the skeleton of an electric bus, such as roof and side pillars and details of the windshield. The research was conducted static and cyclic bending tests sandwich samples whose composition corresponded to perform sandwich roofs. It was conducted static test load roof segment and material identification of windscreen. The obtained data was used for the verification of numerical simulations carried out at the FEM model of the car.

Keywords: Electrobus; Sandwich Roof; 4PB Test; Fatigue Test.

1 Introduction

Use of new materials in the construction of many products is motivated by an effort to increase their usefulness. Sandwich structures with various combinations of core and faces are used in transport industry [1]. Reduction of total weight of electric bus is the main goal, which allows among others to increase the useful range of the electrobus with the same electric equipment. This was solved as part of the project coordinated in cooperation with the firm VISION CONSULTING AUTOMOTIVE and the manufacturer SOR Libchavy. Efforts to achieve efficient and lightweight design can be divided into several steps, choice of sandwich roofs and select the appropriate version, the question of the use of better performing materials with traditional construction, verification of the final solution numerical and experimental manner on the roof segment. The main criterion is then fulfilling rollover testing at the lowest weight of the skeleton of the vehicle.

2 Tests of basic structure

2.1 Static bending test of sandwich specimen

With regard to previous research [2] final combination of sandwich structure consisting of a core of PVC foam and covers made of aluminium alloy was chosen. Beam specimens that option was made by sandwiches technology prototype production, which later proved as problematic factor.

Sandwich beams were subjected to four-point bending test see Fig. 1. All types of samples had the same core – PVC foam with density ca 60 $kg{\cdot}m^{-3}$. Specimens Foam A and Foam F faces were made of steel, specimens Foam D [2] faces were made of stainless steel. Top face of specimen Foam E were made of stainless steel and bottom were made of dural alloy. Both specimen Foam G faces were made of dural alloy. Results can be compared even with earlier variants see Fig. 2. Stiffness of various specimens corresponds faces materials. Specimen Foam A and Foam F are stiffer than specimens Foam D, F and G. Results static tests were affected by higher variance of strength caused by different types of failures when some samples were poorly glued.

Model sandwich roof will be used for calculations of behaviour of the bus body using FEM software ABAQUS. The PVC foam was modelled as an isotropic material with linear 8 node elements. Adhesive joint between the core and the faces was modelled using cohesive elements. Numerical model of 4PB tests verify the suitability of the selected elements and material properties. Static bending tests of sandwiches were numerically simulated by FEM.

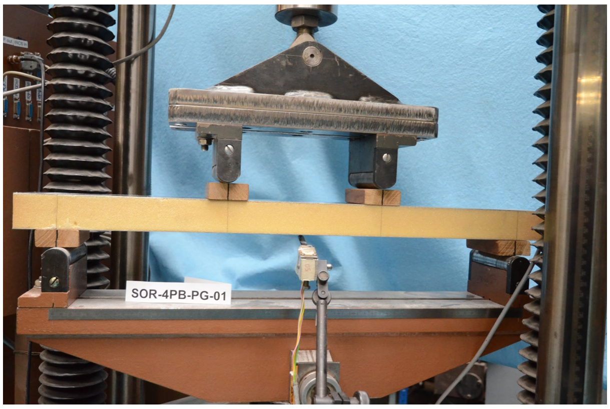

Fig. 1: Static test of 4PB of sandwiches.

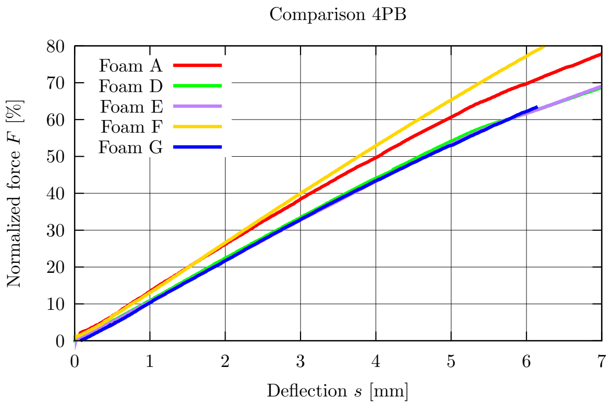

Fig. 2: Comparison results of static test.

2.2 Fatigue bending test of sandwich specimen

Based on the a static test the initial level of fatigue tests had been set, but the results of fatigue tests were affected by different types of failures the cause of the uneven quality of sandwiches prototype production. Scheme of the fatigue test is in Fig. 3. The results of fatigue tests show greater variance similar to the static test, again caused by apparently non-constant production quality of prototype specimens.

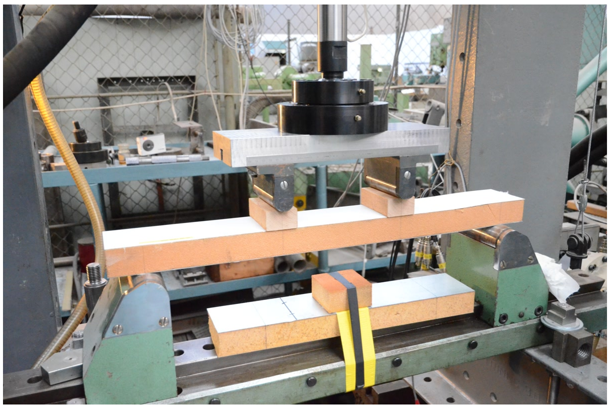

Fig. 3: Fatigue test of 4PB of sandwiches.

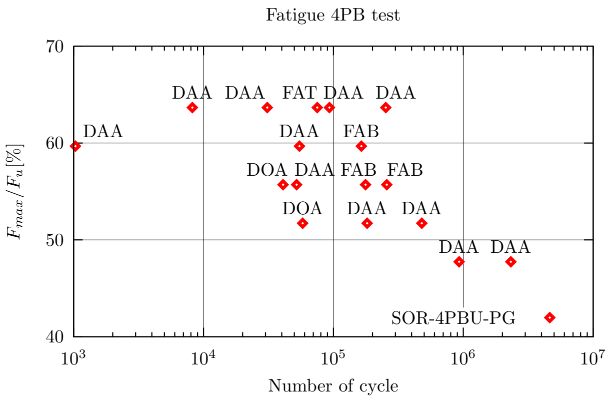

Fig. 4: Results of fatigue test.

The results of fatigue experiments are plotted in the graph in Fig. 4. Types of defects are marked in accordance with standard ASTM C393 [3], when F in the first place represents facing failure D in first place represents skin to core delamination. Second code is failure area, when A means at load bar and O means outside gauge. Third code is failure location, when A means core–facing bond, T means top facing and B bottom facing. Examples of failures can be seen in Fig. 5 and 6.

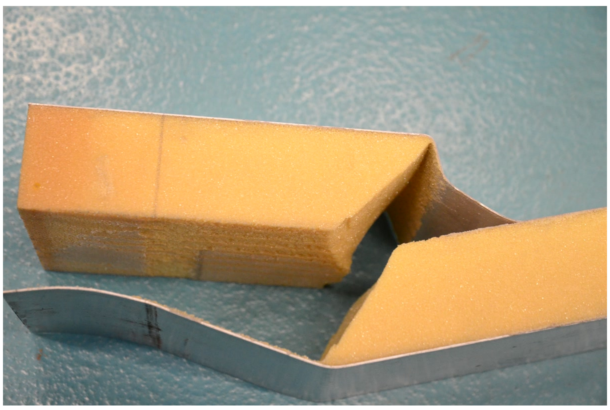

Fig. 5: Example of DOA failure.

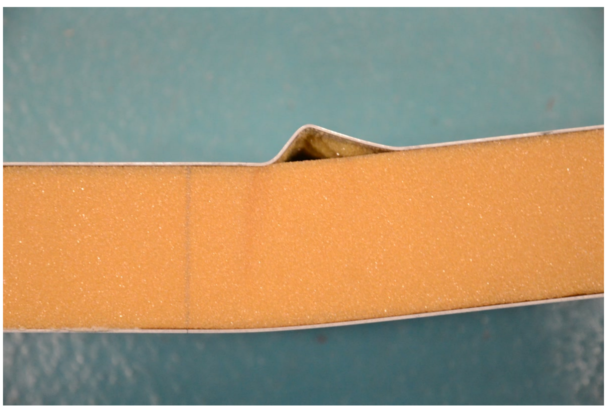

Fig. 6: Example of DAA failure.

2.3 Bending test of duplex profile

The side pillar is one of the other elements of the structure affecting the safety of the vehicle rollover accident. Three point bending tests (see Fig. 7) the connection side and window (scheme see Fig. 8) pillar were made to verify the numerical calculations. Different combinations used sections and variations of structural modifications with respect to higher loading capacity from loss of stability of the structure were investigated.

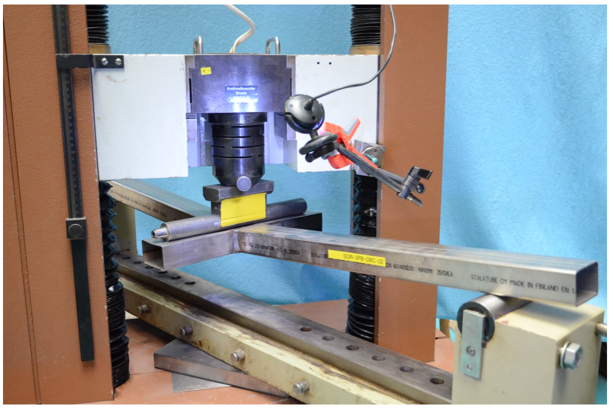

Fig. 7: 3PB test of duplex profile.

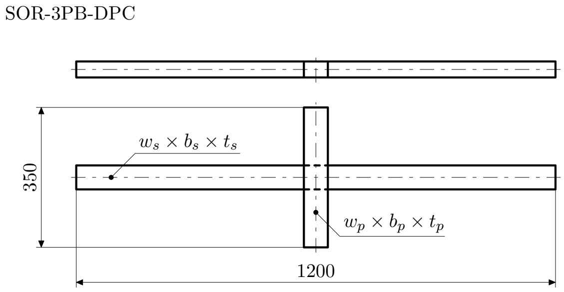

Fig. 8: Test specimen scheme.

2.4 Windscreen tests

Windscreen material properties is important parameter for tuning the numerical calculation of the electric bus rollover test. To verify the properties of glass in the numerical model tests of windscreen were made. The flexural properties were obtained by four points bending test see Fig. 9. The test was numerically simulated with good agreement between experiment and numerical calculation.

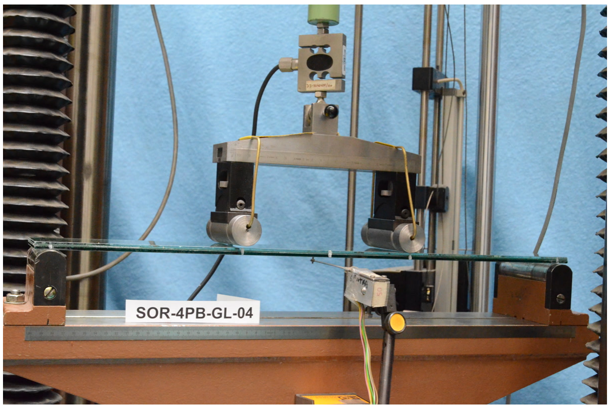

Fig. 9: Bending test of windscreen specimen

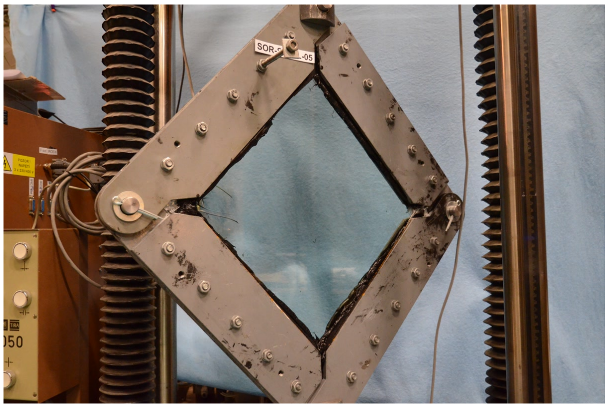

Fig. 10: Shear test of windscreen.

Shearing test was designed to simulate shearing load of glass based on the shear tests of composite panels see Fig. 10. Polyurethane adhesive was used to connect glass with loading fixture. The rate of cure adhesives emerged as a major influence on the results of shear tests, the tentative results show a large variance. Research in this area will continue.

3 Test of electrobus roof segment

To assess the resistance of the entire system, experiment of roof and side pillars was designed, when was loaded roof segment with a length of 700 mm with side pillars. The segment was loaded by a hydraulic actuator, when the force and the displacement of the piston rod were monitored. Loading force direction corresponded to the initial direction of the contact force during the bus rollover test. Segment after the test is shown in Fig. 12. Two type of specimen's were tested, specimens Segment-01–03 have not overlap panel between roof and side profile, specimens Segment-04–06 were complemented with overlap in this location.

Numerical model tests of roof segment was created and the results obtained correspond to experiment, when first FEM model corresponds to situation without overlap and second model was designed with overlap. Results of roof segments experiments and numerical simulation were plotted in Fig. 11. It can bee seen, that overlapping has no significant effect on the strength of the segment. Plastic hinge pillar was the result of test, sandwich roof carry introduced load without significant damage.

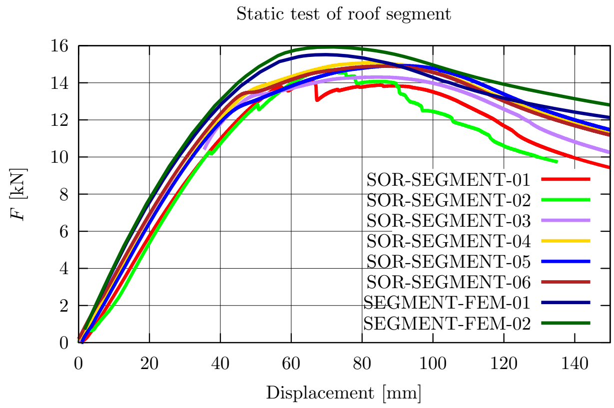

Fig. 11: Roof segment test – comparing experimental and numerical results.

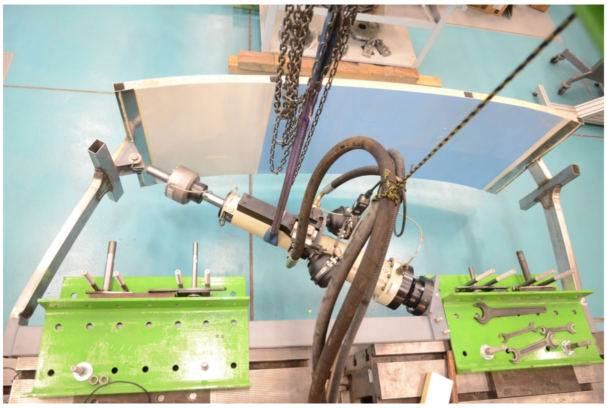

Fig. 12: Electrobus roof segment experiment.

4 Conclusion

Experiments and numerical calculation of basic elements were carried out. It was confirmed carrying capacity of the roof designed variants bus and validated numerical solution useful for further development. An important result of testing is needed to control technology in production to achieve roofs represent a consistent properties with regard to fatigue loading.

Acknowledgement

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References

[1] Fojtl, L. - et al.: Evaluation of Mechanical Performance and Failure Modes of Sandwich Structures for Transport Industry . In Experimental Stress Analysis 2015. Prague: Czech Technical University, 2015, p. 94-97. ISBN 978-80-01-05734-6.

[2] Doubrava, K. - Novotný, C.: Static and Fatigue Testing Sandwich Segment of the Bus Roof. In Experimental Stress Analysis 2015. Prague: Czech Technical University, 2015, p. 66-69.

[3] ASTM International: C393/C393M 11 Standard Test Method for Core Shear Properties of Sandwich Constructions by Beam Flexure [online], [cit. 2012-11-29], Accessible from URL: <http://enterprise.astm.org/SUBSCRIPTION/NewValidateSubscription.cgi?C393/C393M-HTML>.

[4] Doubrava, K.: Static and Cyclic Tests of Sandwich Parts. [Report]. 2015. 12105/2015/26. 26 p. (in Czech).

[5] Doubrava, K.: Bending and shear tests of the windscreen and bending tests reinforced profiles [Report]. 2015. 12105/2015/18. 20 p. (in Czech).