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Experimental and Numerical Analysis of the Bus Sandwich Roof

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Abstract. This paper describes the design verification process of a new bus roof. The aim was to obtain a roof comparable or better mechanical properties with likely dropped weight. The sandwich roof is developed in the framework of the project when properties matching real roof were compared to test samples. Different core materials and faces have been investigated. The results serve to verify the FEM models designed to verify the characteristics of the whole structure of the roof.

Introduction

Reduced fuel consumption is one of the objectives of the efforts of manufacturers of all of vehicles and so it is even buses. Reducing the weight of the skeleton of the bus is one of the options to reduce fuel consumption. The roof of the bus is an important structural element of the structure and each weight savings per unit roof area may have a significant impact on reducing the weight of the complete bus.

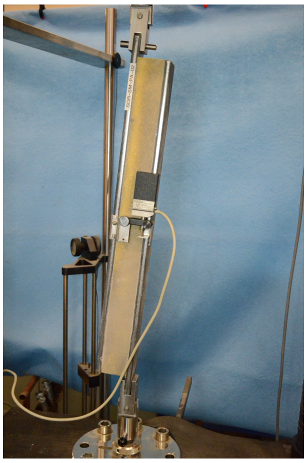
This project is cooperated with firm VISION CONSULTING AUTOMOTIVE and the bus producer SOR Libchavy. The original roof of SOR bus was made up of a metal frame with a laminate coating. The new cantilevered roof is made up of a sandwich. Different variants of the core material were examined during development. There were several criteria for the selection of the material of core and faces like as price, technology, strength and stiffness.

Polypropylene honeycomb was used for sandwich core material in the first stage. Material tests especially at higher temperatures were not satisfactory [1], therefore PVC foam was used in subsequent stages. Metal plate is used for a sandwich face. More complicated constructive shape of the roof with regard to the available technology led to the connection of sandwich relatively flat section of the roof arch made of high-strength steel profile. Individual variants were experimentally tested, the results of experimental analysis was then used to tune the numerical model that was used for the analysis of the entire skeleton of the bus.

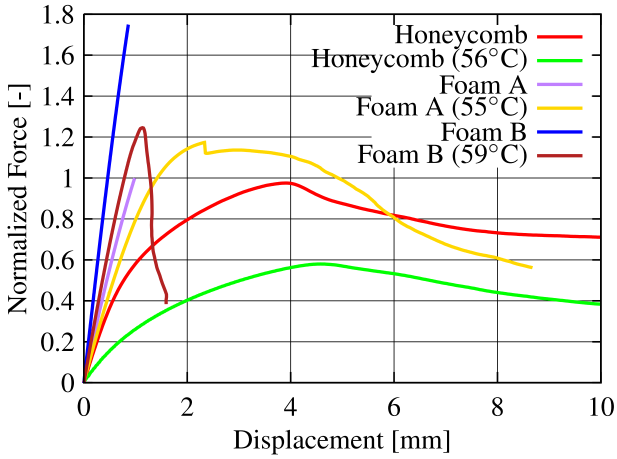
Experimental Analysis

Testing the entire roof would be in the initial stage, it was very expensive, and therefore the tests were carried out on beam specimens. Bending stress is dominant for roof loads, hence four-point (4PB) and three-point (3PB) bending tests were basic comparative experiments [2].

Tensile compressive and shear tests have been carried out to determine the material properties of the sandwich, when standards ASTM C365 and ASTM C273 were used. Effect of temperature was studied in shear tests. Our laboratory is not equipped with a temperature chamber on the load machine. Samples for the shear test (Fig. 1(a)) consist of core material and loading plates which are made from thick sheet metal. To obtain information, the influence of temperature on the mechanical properties of the core with the used adhesive test was conducted when the sample was maintained at 80°C in a curing oven. The test was performed immediately after extraction of the sample from the oven when the temperature was monitored throughout the test using a platinum thermometer. Comparison of tested samples of different core and temperature can be seen in Fig. 1(b). The figure shows a significant dependence of the properties of PP core on a temperature of the test sample, unlike PVC foams, the effect is not so significant. The results of this test were one of the reasons why the next phase of recourse to a PVC foam core of the sandwich bus roof.



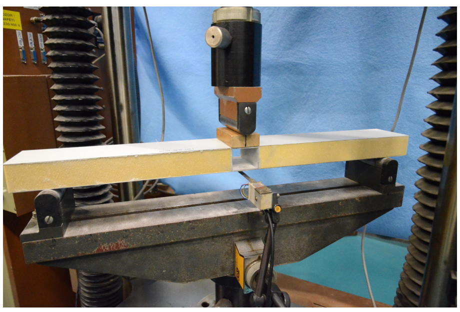
(a) Shear test of Foam A.



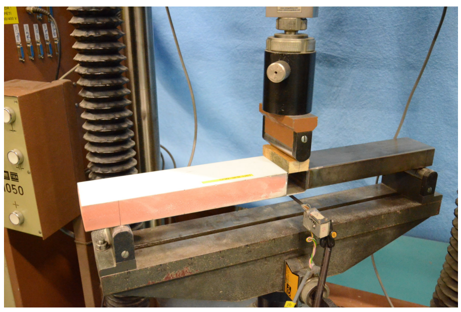
(b) Displacement of loading plates versus norm. force

Fig. 1: Shear test – comparison of core materials and temperature influence

The thickness of the sandwich specimens corresponded to real thickness of the roof, the other dimensions were determined by limitations of the test equipment. PP honeycomb and PVC foams with different density were used for core material. Specimen Foam A has foam density about 60 kg/m^3 and Foam B about 90 kg/m^3. Faces of both type of specimens are made from steel sheet. Specimen Foam C has same material of core like specimen Foam A, but bottom face was made from aluminium sheet. Connecting two faces and a connection to the sandwich section of the metal necessitated the use of structural nodes, which were also examined specimens Str. Node A (Fig. 2(a)) and Str. Node B (Fig.2(b)).



(a) Str. Node A.

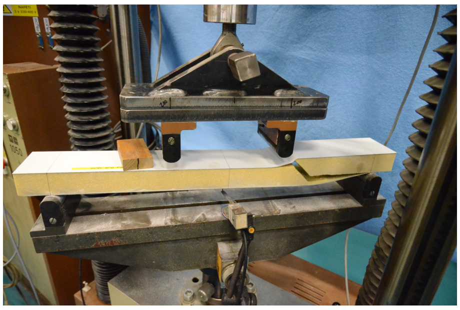


(b) Str. Node B.

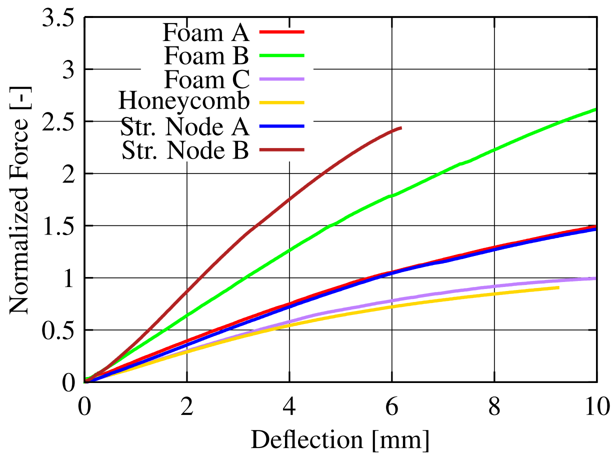
Fig. 2: 3PB tests of structural nodes

Bending tests were carried out on a universal testing machine, the loading was done in a controlled cross-head displacement. Deflection of the beam was recorded using a strain gauge displacement transducer, which was connected to a strain gauge unit. The load was synchronised by connecting the voltage output from the load machine to the strain gauge unit.

Bending tests were performed according to standards ASTM C393 and ASTM D7249. Finished 4PB test of specimen with typical damage can be seen in Fig.3(a). Comparison of tested samples of different kinds can be seen in Fig. 3(b).



(a) Specimen Foam A after 4PB test.



(b) Measured data.

Fig. 3: 4PB tests comparison.

From the test results follows that using of aluminium sheet on the bottom faces is the bending stiffness sandwiches almost half steel face in the use of PVC foam with the same density (Foam A $\times$ Foam C) and the bending stiffness of the sample with a structural node (Str. Node A) is comparable with the stiffness of the fully sandwich sample (Foam A).

Numerical Analysis

Numerical models of the test samples Str. Node A and Str. Node B were created [3] due to tuning feature of the sandwich roof. Model sandwich roof will be used for calculations of behaviour of the bus body using FEM software ABAQUS.

The foam was modelled by isotropic solid 8-nodes linear element with reduced integration, skins and profiles were modelled by continuum shell elements with 8-nodes quadratic thick and reduced integration. Cohesive elements were used for the model of bonded joints. Cohesive elements allow modelling of initial loading, damage initiation and damage evolution leading to eventual fracture [4]. The behaviour of the adhesive joint can only be described as linear elastic with stiffness, which is penalised as the material degrades under tensile and shear loads. Pressure load doesnt affect stiffness. In the case of a three-dimensional problem model considers three components of the interfaces separation (the normal component to the interface, two component parallel to the interface) and three corresponding components of stress in the material section. Cohesive elements operate with nominal stress and strain. The nominal stress is defined as the ratio of the force component and the initial cross-section at each element integration point. Nominal strain is defined as the ratio of separation of the bonded surfaces and the initial thickness of the adhesive at each element integration point. Elastic behaviour is expressed by the elastic constitutive matrix that relates the nominal stress to the nominal strain. Adhesive joints were modelled between foam core and steel skins and aluminium profile (Str. Node A) and joints foam and skins and joint of sandwich part and steel part of specimens (Str. Node B).

Simulation models of the loading were carried out under a quasi-static elastic-plastic analysis minded geometric non-linearity. The models are loaded by the force and with boundary condition in accordance with the experiments. The results obtained from FEM model of Str. Node A corresponded to the experimental data in the elastic region. Numerical model B from the experiment differed by several tens of percent. The differences were probably caused by a complex shape of joints of sandwich and steel parts of the sample with poorly describable thickness of the bonded joint.

Conclusions

Several series of tests of various sandwich structures was carried out. The results of these tests were used to select a combination of materials to be used for the production of sandwich roof. Polypropylene honeycomb was removed because of the reduced stiffness of the sandwich beam corresponding to the model of the roof. In case of increased temperature the decrease in stiffness of PP honeycomb more dramatic than in the case of PVC foams. In respect to the technological limitations in the manufacture of sandwich roof construction must be used structure node. Of course the bending tests showed that Str. Node A essentially does not affect the stiffness characteristics of the sandwich roof. Stiffness and strength of sandwich samples with foam (Foam A) match results Str. Node 1 samples. The numerical model has been tuned for use on the model of the entire bus. Cyclic testing of selected structural variants sandwiches are scheduled.

Acknowledgement

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