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Testing of adhesive joints in sandwich structures

Ctirad Novotný[a]*, Karel Doubrava[a], Milan Růžička[a]

[a]Czech Technical University in Prague, Faculty of Mechanical Engineering, Technická 4, 166 07, Prague, Czech Republic

Abstract

This paper describes the design and the verification chain for sandwich structure using the example of the vehicle sandwich roof. This contains determination of the mechanical characteristics for sandwich core including adhesive, tests of mechanical properties of sandwich specimens and sandwich structure nodes and finally verification of the selected solution on the global sandwich structure (roof segment). Experiments are used for tuning and verification of numerical analyzes suitable for the use on global construction.

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Keywords: Sandwich structure; adhesive joint; bending test; insert; pull-out test; cohesive element.

1. Introduction

Composite structures are increasingly used in transport applications. Their advantage is low weight compared to traditional materials. Their composition can be optimized with respect to the anticipated straining. One type of composite structures is sandwich structure. Sandwiches have excellent ratio of bending stiffness and weight. They are usually composed of three main parts: the two outer relatively thin and stiff skins and thicker softer inner core. The skins are connected with the core to allow transfer of loads between parts of sandwich structure. The core transmits primarily shear forces and skins bending load. High bending stiffness is due to distance of stiff skins and low weight is achieved by using a lightweight core. Individual parts of the sandwich structure are connected by

* Corresponding author. Tel.: +420-224-352-525
E-mail address: ctirad.novotny@fs.cvut.cz

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bonding. This paper describes the procedure for testing adhesive joints within the sandwich applications of vehicle structure (bus or tram roof) and verification of numerical simulations carried out by finite element method (FEM). Adhesive joints are applied in the construction of sandwiches for connection of skins with the core. Furthermore, the adhesive joints are used for solving of connecting bolted joints using inserts in a sandwiches.

2. Methodology

The different types of the sandwich bonded structures have been tested: (i) sandwich beams, sandwich structural nodes, segments of vehicle roof and (ii) sandwich plates with insert for bolt connection. It was proposed design chain based on the testing and verification of numerical simulation for adhesive joints in simple structures with subsequent extension to a global adhesive structures.

2.1. Solution procedure

Solutions can be divided into the following steps:

- Determination of material characteristics of the sandwich materials and adhesives for sandwich design and numerical simulation.
- Experimental tests of the mechanical properties of local and global sandwich samples, evaluation of stiffness and strength.
- FEM numerical simulation and its verification by experiment.

2.2. FEM numerical simulation

With regard to the geometry and the relative size of each component sandwich structure can be discretized by solid or shell elements. On the basis of comparative analyses for beam deflection there was chosen variant with core modelled using solid and skin shell elements [1]. Linear elastic model was used for core and skins. For the modelling of adhesive layers there were used special cohesive elements. The mechanical response of these elements is described using dependency nominal stress - nominal strain. Cohesive elements allow modelling of initial loading, damage initiation and damage evolution leading to the eventual fracture. Elastic behavior is expressed by means of an elastic constitutive matrix that relates the nominal normal and shear stress to the corresponding nominal strain in relation

$$\begin{bmatrix} t_n \\ t_s \\ t_t \end{bmatrix} = \begin{bmatrix} K_{nn} & K_{ns} & K_{nt} \\ K_{ns} & K_{ss} & K_{st} \\ K_{nt} & K_{st} & K_{tt} \end{bmatrix} \begin{bmatrix} \varepsilon_n \\ \varepsilon_s \\ \varepsilon_t \end{bmatrix} \tag{1}$$

Vector of nominal stress consists of normal stress t_n and two shear stresses t_s, t_t, vector of nominal strain consists of normal strain ε_n and two shear strain ε_s, ε_t. In the case that the different modes of loading (normal and shear) do not affect each other or it is negligible, the off-diagonal elements of the constitutive matrix are zero. This consideration was used for solution of described sandwich problems. Damage evolution is based on concept of effective displacement [2].

3. Sandwich structure – local and global specimens

Bending tests of sandwich beams and sandwich structural nodes were designed to describe the behaviour of composite structures. Sandwiches consist of sheet metal skins (top face steel – thickness 0.5 mm, bottom face duralumin – thickness 0.8 mm) and foam core Airex C70.55 (density of 60 kg·m^{-3}, thickness 40 mm). They are