# Numerical models of sandwich panels with soft core

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Abstract

Two classes of numerical models of sandwich structures are discussed, namely 2D and 3D. The latter ones must be applied for the analysis of the local phenomena of wrinkling and debonding. Numerous laboratory tests were performed on the component materials and full scale panels with the aim of the verification and validation the proposed numerical models. A number of numerical simulations were carried out and the most efficient and robust models are proposed. Particular attention was paid to the problem of local instability of compressed facing in bending, the phenomenon of progressive damage and the influence of geometrical and technological parameters of the panel.

*Keywords: composites, sandwich structures, finite element methods, experimental mechanics, stability*

## 1. Introduction

Sandwich structures are commonly used in various branches of industry. They are usually made of three layers: rigid external faces and flexible core. The facings can be flat, micro-profiled or deep-profiled. The sandwich panels are very attractive because of high load-bearing capacity at low self-weight, excellent thermal insulation and possibility of economical mass production. However, the description of the structural behaviour of sandwiches should take into account various failure mechanisms, essential role of temperature actions, influence of creep, shear flexibility of the core and high susceptibility to local instability of compressed faces.

Sandwich structures are very often analysed by practical engineers using the model of isotropic plate or beam [3]. The classical shear deformation theories are presented in [9]. These theories result in continuous shear strains and discontinuous shear stress across layers. Another group constitute discrete-layer theories which overcome the drawback of stress discontinuities. This approach is studied by Aitharaju and Averil [1] and others. Different, consistent approach is proposed by Frostig. Global and local effects are considered simultaneously in the theory. The numerical examples basing on the approach are presented in [4].

The nonlinear interactions in the problem of local and global instability was presented by numerical examples in [6]. Numerical and experimental investigation of structures subjected to local buckling effect was discussed in [7, 8]. The important phenomenon of stress concentration and complex interactions between facings and core part was observed and described by Kim and Dharan [5]. The influence of the core shear rigidity on the sandwich behaviour was presented in [2].

The aim of the paper is the proposal of the most efficient and robust numerical 2D and 3D models. Note that 2D models are widely used in practical design for the global analysis. However, they must be properly calibrated to ensure the required accuracy. Precise analysis of the local damage mechanisms needs the implementation of refined 3D modelling. The proposed 3D FE models take into account bending, shear, support capacity, local stability and debonding effects. In the present study special attention is paid to the proper choice of the interface model. These models use a number of material parameters, which should be determined experimentally.

## 2. Experimental tests

The subject of our studies is a sandwich structure, which consists of polyurethane core and external steel facings. The main part of the tests was carried out on panels with flat or micro-profiled facings. The total depth of the sandwich was 0.10 m, whereas the nominal thickness of the facings was 0.5 mm. The bending tests were conducted using two devieces: the vacuum box simulating uniform suction of the plate and the apparatus which extorts line loads. In order to measure strains, 3 to 12 tensometers were attached to each specimen. The global response was monitored by load and displacement devices.

The aim of the study was the estimation of the influence of geometrical and technological parameters of the panel as also boundary conditions on the value of wrinkling stress. Therefore, the following tests on one-span systems were realised:

a) flat panel without edge profiling, external side in compression, suction,
b) flat, without profiling, internal side in compression, suction,
c) micro-profiled (linear), without edge profiling, external side in compression, suction,
d) flat, edge profiling, external side in compression, suction,
e) flat, without edge profiling, internal side in compression, line load pressure (simulation of multi-span system),
f) flat, without edge profiling, external side in compression, line load suction (simulation of multi-span system).

The wrinkling stress for systems a-f are presented in Table 1.

Table 1: Wrinkling stress of panels in bending

| System | Specimen symbol | Wrinkling stress [MPa] |
|---|---|---|
| a | FF bz 1 | 151.65 |
| b | FF bz 2 | 120.65 |
| c | LL bz 3 | 194.96 |
| d | FF 4 | 161.31 |
| e | FF bz 5 | 91.28 |
| f | FF bz 6 | 90.54 |

The bending tests enabled the evaluation of shear modulus of the core. The values were compared with the results received from shear tests on short panels (measurement of displacements or angle of rotations), double-lap shear tests and torsion tests.

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All of the results were used in calibration of the numerical models and estimation of their accuracy.

### 3. Numerical modelling

In the numerical simulations the parameters of the structures correspond to the experiments. They were prepared in ABAQUS system environment. The simulations were started with the application of the 2D model. The structure was created using *shell section* definition and elements of type S8R. The *shell section* with the option *composite* allows definition of multilayered structure with various thickness, number of integration points and material for each layer. The S8R is 8-node, doubly curved thick shell element with reduced integration. Therefore, it is appropriate for analysis of thick, shear deformable plates. The received results were compared with classical solutions given in [3, 9].

The next step was creation of basic model 3D. Steel, flat facings were assumed as elastic - ideal plastic material. The material parameters following the experimantal results were used: Young modulus $E_F$ = 195 GPa, Poisson ratio $\nu_F$ = 0.3 and yield stress $f_y$ = 280 MPa. Facings were modelled using four node, doubly curved, thin or thick shell, reduced integration, hourglass control, finite membrane strain elements SR4. The core of the panel was modelled using eight node linear brick elements C3D8R. The core was defined as homogeneous isotropic, elastic material $E_C$ = 8.65 MPa, $\nu_C$ = 0.02. Interaction between all parts was assumed as TIE type, which makes equal displacements of nodes.

Among various damage mechanisms we are particularly interested in wrinkling (local buckling) of a compressed face in bending. To achieve the local effects for various geometrical conditions (shell and edge profiling), the 3D model was improved. The geometry of profiling was precisely introduced. Between the facings and the core, a layer of interface was introduced. The interface was modeled using COH3D8 8-node, 3D cohesive elements. The elasticity uncoupled law for cohesive material of the interface was used:

$$\begin{bmatrix} t_n \\ t_s \\ t_t \end{bmatrix} = \begin{bmatrix} K_{nn} & 0 & 0 \\ 0 & K_{ss} & 0 \\ 0 & 0 & K_{tt} \end{bmatrix} \begin{bmatrix} \varepsilon_n \\ \varepsilon_s \\ \varepsilon_t \end{bmatrix}, \qquad (1)$$

where $t_n$ is normal traction (stress) and $t_s$, $t_t$ are shear tractions. Corresponding nominal strains are defined as $\varepsilon_n = \delta_n/T_0$, $\varepsilon_s = \delta_s/T_0$, $\varepsilon_t = \delta_t/T_0$ using separation $\delta$ and constitutive thickness of cohesive element $T_0$.

The debonding phenomenon is conditioned by stress and strain states. Most examples were done for quadratic nominal stress criteria of damage initiation and displacement type with linear softening damage evolution. Damage initiation criterion has the form

$$\left\{\frac{\langle t_n \rangle}{t_n^0}\right\}^2 + \left\{\frac{t_s}{t_s^0}\right\}^2 + \left\{\frac{t_t}{t_t^0}\right\}^2 = 1, \qquad (2)$$

where $\langle . \rangle$ is Macaulay bracket with the usual interpretation.

The numerical example of the wrinkling of compressed facing is demonstrated in Fig. 1. The figure shows normal stress along $x$ axis. The wrinkles are visible in the whole area, but the stress concentrations associated with the debonding have very local form.

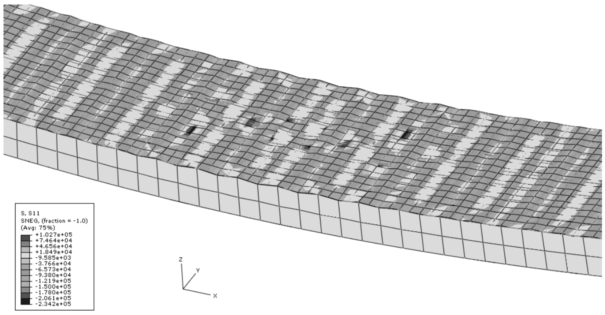

Figure 1: Distribution of normal stress in panel with flat facings

### 4. Concluding remarks

Proposed numerical models are useful in the analysis of sandwich panels taking into account different classes of phenomena. The 2D model is suitable for the estimation of global response, whereas the proposed 3D model proved to be able to simulation of wrinkling and local damage. It is very important because these local effects are very sensitive to variations of material parameters and boundary conditions.

The laboratory tests were planned to provide information which can be used in validation of numerical models. The experiments allowed determination of appropriate material parameters and observation of the structure behaviour.

It is worth to mention that the proposed 3D model enables introduction of local imperfections of facing geometry and local lack of adhesion between core and facing. The developed models can be used in numerical simulation of experiment thus significantly minimizing number and cost of laboratory tests.

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