Failure mode prediction for composite structural insulated panels with MgO board facings

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Abstract

Sandwich panels are readily used in civil engineering due to their high strength to weight ratio and the ease and speed of assembly. The idea of a sandwich section is to combine thin and durable facings with a light-weight core and the choice of materials used allows obtaining the desired behaviour. Panels in consideration consist of MgO (magnesium-oxide) board facings and expanded polystyrene core and are characterized by immunity to biological corrosion, a high thermal insulation and a low impact on environment. Customizing the range of panels to meet market needs requires frequent size changes, leading to different failure modes, which are identified in a series of costly full-scale laboratory tests. A nonlinear numerical model was created, with a use of a commercial ABAQUS code and a user-defined procedure, which is able to reproduce observed failure mechanisms; its parameters were established on the basis of small-scale tests and numerical experiments. The model was validated by a comparison with the results of the full-scale bending and compression tests. The results obtained were in satisfactory agreement with the test data.

Keywords: sandwich panels, magnesium oxide board, expanded polystyrene, FEM analysis, nonlinear analysis, failure modes

1. Introduction

A composite structural insulated sandwich panel (CSIP) is an advanced, modern approach to the idea of sandwich structures. It is based on the fundamental idea of combining two materials with different qualities – a light-weight, thick, core with high thermal insulation properties, sandwiched between two high-strength, durable and thin facings, joined together by an adhesive of sufficient strength [2]. CSIP's facings are made of composite materials, what makes them considerably stronger, immune to biological corrosion and more durable to weather conditions. Such desirable improvements, in comparison to traditional SIPs with wood-based facings, make CSIPs a very attractive alternative with a broader field of applications [3].

The report describes a specific type of CSIPs with MgO board facings reinforced with fiberglass and an expanded polystyrene core (Fig. 1), characterized by high thermal insulation and low impact on environment. This is a new product that requires adjusting its assortment to market needs, leading to frequent changes in its dimensions: length, width, and layers' thickness. Due to the complex nature of layered structures, consisting of materials of diametrically different characteristics, this leads to difficult-to-foresee changes in their behaviour and requires a cycle of costly laboratory tests on full-scale panels.

In order to create a numerical model, which allows for a reliable description of the behaviour and failure modes of panels of different geometries subjected to different types of loads, a series of laboratory tests was performed [6]. In the small-scale laboratory tests mechanical properties of constituent materials were measured, failure modes of samples of different geometries and layer arrangements subjected to different loadings were identified, and important physical phenomena were distinguished. Based on the full-scale tests, failure modes of wall panels subjected to compression and bending were determined and the similarities and differences in behaviour of small samples and full-scale panels were observed [4,6]. Using commercial ABAQUS software [1] a numerical plane stress model was developed [4,5,6].

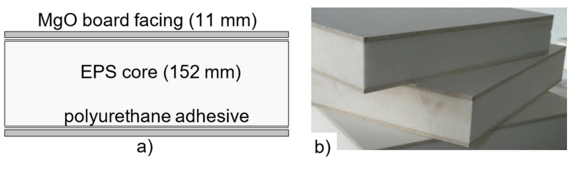

Figure 1: Analysed CSIP: a) scheme, b) view

2. FEM model description

The numerical description of analysed CSIPs was based on the results of small-scale tests. The behaviour of tested samples showed, that material nonlinearity of both, the core and facings has to be taken into account. For this purpose the Drucker-Prager yield function, with separate sets of parameters for different layers, was used [4,5]. Trial FE analyses indicated that the low stiffness of the core material leads to significant deformations and so geometric nonlinearity has been taken into account as well. All tested samples have lost their load-bearing capacity with the initiation of damage, so failure was modelled by initiation criterion only, without defining damage evolution behaviour. A ductile damage criterion, based on the stress triaxiality and the equivalent plastic strain, was used.

Some material properties for elastic and plastic range were obtained directly from the experimental data, some were identified in a series of numerical simulations carried out in such a way to obtain satisfactory consistency with results of 15 different small-scale tests: compression, tension, direct shear and bending of EPS, bending of MgO board, compression and bending of CSIP samples of different geometries. Damage initiation criteria parameters were obtained as results from abovementioned simulations, corresponding to fracture loads of individual samples. Due to a large dispersion of MgO board strength properties (Fig. 3), two sets of parameters were defined, corresponding to a lower and an upper limit.

It was observed, that both materials' behaviour is strongly dependent on the stress state, therefore a user-defined procedure was developed [4,5], which produces a state variable f_σ assuming values from –1 to 1, which correspond to states of

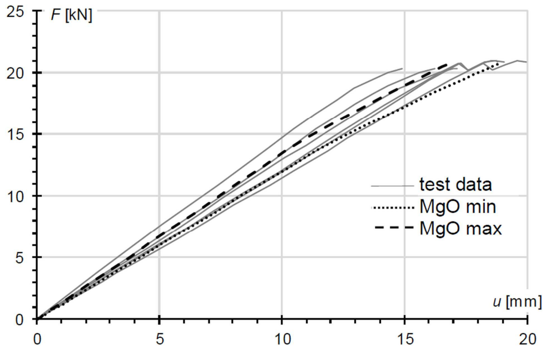

Figure 2: Force - displacement curves in full-scale bending

biaxial compression and biaxial tension respectively. Different sets of material properties assigned to selected values of f_σ were prepared for the elastic range, the plastic range and the failure initiation.

All simulated samples were modelled with 4-node plane stress elements with a reduced integration and hourglass control. The supports were substituted with rigid body planar wire sections and a low friction contact interaction was used between the rigid parts and the sample. Pinned boundary conditions were created at a single reference point assigned to each rigid profile.

3. FEA results

The final model was validated by a comparison with the results of full-scale bending and compression tests. Two CSIPs of dimensions (in mm): 2500×1000×174 were subjected to four equally distanced line loads, normal to panels' midsurfaces and of equal intensity [4,6]. The comparison of the vertical deflection in the mid-span obtained from laboratory tests and numerical simulations is shown in Fig. 2. The numerical model reflects general character of the experimental curves very well, but different sets of failure criterion parameters in tension were obtained for small-scale bending of MgO board, CSIP samples and full-scale panel due to size effect. Failure initiation properties in the facing tension obtained for different samples are compared with small-scale MgO board bending experimental data in Fig. 3. It can be seen, that failure of full-scale panel corresponds well with the proportionality limit of MgO board sample and that this value should be used instead of small-scale facing's limit strength.

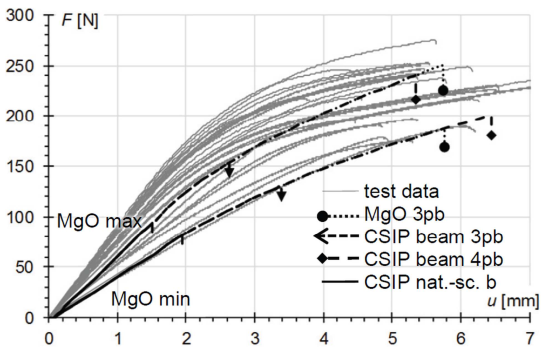

Figure 3: Force - displacement curves in MgO board bending

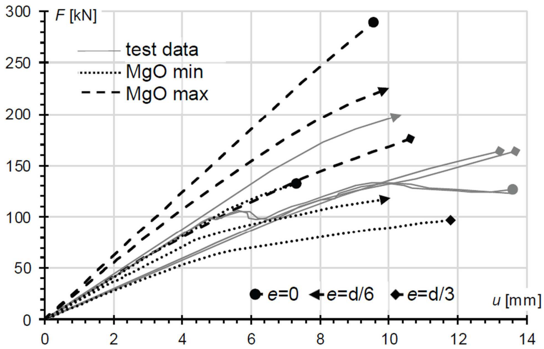

Figure 4: Force - displacement curves in full-scale compression

Three CSIPs of dimensions (in mm): 2750×1000×174 were subjected to edgewise compression with different values of the load eccentricity: e=0, e=d/6 and e=d/3, where d is the panel's thickness [5,6]. Figure 4 shows that laboratory test results fit well within the numerical prediction range in both: the curve shape and the failure load. The model was even able to predict the premature failure of the panel submitted to uniaxial compression, which coincides with the lower limit of MgO board compression strength properties. The numerically obtained curves indicate that the failure load is decreasing with the increase of the eccentricity value, as expected.

4. Conclusions

The final model validation by a comparison with the full-scale tests gave results that are satisfactorily consistent with the experimental data, both in terms of the nature of the curves obtained and the observed mechanisms of failure. The model allows for a prediction of full-scale CSIP failure modes, based on appropriate small-scale test data.

Acknowledgements. This work is dedicated to the memory of Professor Liviu Librescu (1930-2007).

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