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An indirect non-linear approach for the analysis of sandwich panels with TRC facings

A. Junes [a], A. Si Larbi [b,*]

[a] LGCIE, Université Claude Bernard LYON 1, 82 bd Niels Bohr, 69622 Villeurbanne, France
[b] Univ Lyon, Ecole Nationale d'Ingénieurs de Saint-Etienne (ENISE), Laboratoire de Tribologie et de Dynamique des Systèmes (LTDS), UMR 5513, 58 rue Jean Parot, 42023 Saint-Etienne Cedex 2, France

HIGHLIGHTS

- Provide a non-linear calculation procedure of TRC-facings sandwich panels.
- Theoretical/experimental confrontation on a global.
- Validation of the model.

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ABSTRACT

The composite material TRC results from the combination of a fine-grained cement matrix and a textile reinforcement. This composite has good mechanical properties and, depending on the nature of the matrix, good acoustic isolating properties and fireproofing can be considered. One of the potential applications of this new generation composite deals with sandwich panels via thin facings. Although studies of TRC sandwich panels are rare, it is the finite element approach which is quite preferred for studying their quasi-static mechanical behavior. Although interesting and useful, this approach requires excellent mastery of computer software given the many nonlinearities that should be included. This paper aims to provide a non-linear calculation procedure of TRC-facings sandwich panels with the following main properties: (i) the use of materials "real" behavior law (ii) the use of numerical methods (iii) the application of arbitrary combination loads and (iv) allowing to study both global and local behavior. This procedure is based on (i) the cross-section and length of the panel meshing and (ii) the non-coupling of bending, shear and local bending effects of the mechanical behavior of the panel. A sensitivity study is further performed to evaluate the evolution of the relative error depending on the mesh size. Finally, using the results obtained from an experimental campaign on TRC-facings sandwich panels, a theoretical/experimental confrontation on a global scale (load-deflection behavior and failure mode) and local (strain development) will be performed. This will permit us, on one hand, to emphasize the good reproduction of the results given by the method on a global scale and, on the other hand, some limitations to the local scale where possible explanations are proposed.

1. Introduction

Sandwich panels such as we know them today were first used in the aeronautical industry [1]. The combination of metal facings and honeycomb cores enabled the production of light, robust structures used almost exclusively in aeronautics (prior to the 1960s). From the 1960s onwards, sandwich panels were introduced for several other applications, particularly as building materials, owing to the high stiffness-to-weight ratio they afford. On top of these advantages, they also offer beneficial properties in terms of thermal and acoustic insulation, easy manufacture, time-saving installation, etc. The most commonly-used panels are composed of a cellular core and two facings. The variety of materials used in manufacturing of the sandwich panel facings is currently rather limited [2–4]. With the development of composite materials such as textile reinforced concrete (TRC), the resulted facings are less vulnerable to indentation problems as it was the case with those made from steel or aluminum.

Moreover, concrete matrix may offer other beneficial properties such as incombustibility and fire-resistance, which allow to considered TRC composites as potentially promising alternatives in the

* Corresponding author.
E-mail address: amir.si-larbi@enise.fr (A. Si Larbi).

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manufacturing of highly performance sandwich panels, with valuable mechanical and fire-proofing properties. The use of TRCs for the manufacturing of sandwich panels is very recent; few scientific studies are to be found in the literature on the subject (e.g. [5–9]).

As regards modeling and calculation for sandwich panels subjected to bending (4 point bending as a rule), there currently exist several approaches, of varying degrees of complexity and sophistication (e.g. [3,5–7,10–13]); in these studies, the finite element method is the most widely-used. For the most part, these models give good results, especially for sandwich panels with facings whose behavior is linear or quasi-linear until failure (steel, aluminum, FRP, etc.).

Although rare, approaches using the modeling of sandwich panels with TRC facings are obliged, in particular, to take account of the loss of overall stiffness due to the multi-fissuring of the mortar-textile composite facing. Cuypers [5] uses the ANSYS program (2D element PLANE 82), to model a sandwich panel subjected to a 4 point bending-type load (up to 2/3 of the panel's maximum capacity), obtaining relatively small deviations (less than 10%, on average, from calculated maximum deflection. Larger deviations are observed in regards of the facing strain at mid-span). Hegger et al. [6] also make use of the finite element method, using the ABAQUS program to model panels fitted with connectors designed to improve the core facing connection, while also taking account of the non-linear properties of the materials. The results display strong correlation between the force-displacement response until failure obtained via the numerical model, and experimental results.

Unlike the studies mentioned in the previous paragraph, Shams et al. [7] propose an analytical calculation model to determine the load-deflection response of a sandwich panel with TRC facings being subjected to 4 point bending-type load. This analytical model, based on the model proposed by Stamm et al. [14], analyzes the sandwich panel responses in terms of two uncoupled components: (i) that due to the bending moment and (ii) that due to the shearing force. For each component, two 4th degree differential equations are solved. The model introduces the cracking of the matrix by modifying continuously the facing stiffness according to the concrete matrix strain for a given load. The authors proposed analytic solutions for calculating the global response of the panel (deflection, resulting forces, etc.) The theoretical-experimental comparison shows that the theoretical load-displacement curve is almost superposed to the experimental counterpart.

What emerges from this brief literature review is that, even if the used modeling procedures give good results, particularly at a structure level, they still have their limitations. In the case of the finite element method [5,6], genuine mastery of the software (which, in addition, is not always free to use) is required to achieve precise modeling of the non-linear behavior of the materials and geometrical non-linearities (choice of the more adapted finite element, mesh size, introduction of matrix cracking, etc.). As shown by Cuypers [5], the results obtained are highly sensitive to the choices made concerning the laws governing the behavior of materials introduced into the numerical model. As regards of the analytical models identified in the literature (e.g. [7]), their main limitations are: (i) the fact of using exact solutions in calculating the global (load-deflection) response of the structure; its scope is thereby limited to particular load patterns (ii) to account for the multi-fissuring of the matrix, the model is relying on homogenized stiffness which is presumed to be identical for each section of the panel, whereas the stresses present in the different sections are in no way uniform.

This paper therefore aims to rectify, even partially, the limitations inherent in using modeling procedures for sandwich panels with TRC facings. The model we propose is a further development of the work done by Sharaf [3] on the study of sandwich panels with GFRP facings (with linear behavior until failure), using the following principles:

- Consideration of the multi-cracking tendency of the materials used for panel facings (Non-linear behavior).
- Use of an adaptive mesh for the length of the sandwich panel and of a layered mesh for the height of the panel (Varastehpour [15], Meaud [16]).
- Consideration of the strain due to local bending of the two sandwich panel facings (upper and lower).
- Use of numerical methods to comprehend global and local behavior (due in particular to the flexibility of the foam).
- Use of arbitrary load patterns and boundary conditions.

With this in mind, the validation of the model we develop is achieved by comparison with the results of experimentation on thin-walled foam-core sandwich panels having a d/t ratio close to 16 (d being the distance between the axis of the facings and t is the thickness of the panel facing). For the in-plane geometry, a Length/Width ratio close to 6 is used. These dimensional ratios are highly realistic, given that they are compatible not only with the most readily available commercial products but also with those used for the purpose of research into the properties of sandwich panels with TRC facings [5–7]. It should also be noted that, according to [5], this geometric ratio allows us to consider transverse strains, and consequently the Poisson effect (on the mechanical behavior of beams), to be negligible. Moreover, the external load (dead weight, wind, etc.) is considered to be applied to the total width of the panel. These various considerations, taken together, means that the mechanical behavior of a sandwich panel may be considered as equivalent to that of a beam being subjected to unidirectional bending.

2. Presentation of the model

2.1. Calculation assumptions

For the purposes of modeling sandwich panels with thin facings (sandwich beam) being subjected to unidirectional bending, we first define the assumptions which underpin the model being developed (in the following, we consider that x-axis is aligned along the panel longitudinal direction, y-axis is aligned along the thickness direction and z-axis is aligned along the width direction):

1. The thickness of the facings is less than that of the core (thin-walled panels). The strains ε_{yy} and ε_{zz}, due to the uniaxial bending of the facings and the core are not taken into account, i.e. $\varepsilon_{yy} = \varepsilon_{zz} = 0$. The strains being considered are: i) longitudinal membrane strains ε_{xx} in the facings and the core, ii) shear strains τ_{xy} in the core and iii) strains in the core $\varepsilon_{xy}^{F.L.}$ produced due to its flexibility (local bending effect).
2. The materials behavior law subjected to tension and/or compression which the panel is composed of may be non-linear.
3. Linear distribution of normal strain ε_{xx} along the height of the panel is taken into consideration. Case of thin-facings sandwich panels.
4. Effects due to the bending moment and the shear force (deflections, strains, forces) are analyzed independently of each other.
5. The adherence or connection between facings and foam are considered as perfect.
6. The strains remain at sufficiently low levels for them to be considered on the domain of small deformations.