Numerical analysis of local buckling of three-layered beams with metal foam core

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Abstract

The main objective of this work is the numerical analysis (FEM analysis) of stability of three-layered beams with metal foam core (alumina foam core). The beams were subjected to pure bending. The analysis was divided into two parts: linear buckling analysis and nonlinear post-buckling analysis. The analysis of local buckling as well as the influence of geometrical parameters of the beam and material properties of the core (linear and nonlinear model) on critical load values and buckling shape were performed. The calculations were made on a family of beams with different mechanical properties of the core (elastic and elastic-plastic material). In addition, the influence of geometrical imperfections on the deflection of the beam and normal stress values of the core and the faces has been evaluated. This work is also the starting point to the further research, including the analytical ones, related to the analysis of local loss of stability of three-layered beams with light foam core.

Keywords: stability, buckling, sandwich beam, FEM

1. Introduction

Multi-layered structures appeared in the mid-twentieth century and, with them, the problem of their stability. They consist of two thin face layers which are separated by the material of the core. The material of the core is thicker and has lower density compared to the material of the faces. However, the faces may differ in thickness, material, or fiber orientation, or any combination of these three. Filler layer is required to provide sufficient stiffness of the construction [1].

Typical design goal for sandwich structures is high bending stiffness combined with low weight, which makes the use of low density core materials desirable. Due to the relatively small transverse normal stiffness of these cores, a considerable loss of stiffness of the sandwich can be caused by local instability phenomena such as buckling of the face layers at short wavelengths. This fact leads to specific design criteria for sandwich constructions [2].

Each construction, including three-layered constructions; regardless of their type: beams, plates, shells; are subjected to load. They become systems, which are sensitive to their geometry, type of material, shape imperfections, character and intensity of load and additional environmental factors. Their properties are strictly related to working conditions [3]. One of the most disadvantageous type of load is buckling.

Buckling of sandwich structures usually causes wrinkling of the faces. Wrinkling is a stability phenomenon associated with short wavelength. Wrinkling phenomenon is important for sandwich constructions having a continuous low-density core material, e.g., a plastic foam. For honeycomb or corrugated cores, this type of instability will not occur in practice, although local buckling of other types (intercell buckling) may occur. The wrinkling may be symmetric or asymmetric with respect to the centre plane of the core [4].

In this paper the results of numerical study of sandwich beams vulnerable to wrinkling are presented. The analysis was divided into two parts: linear buckling analysis and nonlinear post-buckling analysis. First, a linear stability (buckling) analysis was performed to determine the critical load values and to define the relevant buckling modes. Post-buckling analysis allowed to measure the deflection of the beam as well as normal strain values in the core and the faces.

2. Research methodology

The finite element analysis has been prepared with the use of ANSYS software. Due to symmetry of the presented model only a quarter of the beam has been modelled. Tie constrains have been applied between the core and the faces. The upper and the lower face have been retreated from the core by half the thickness. The model was supported to block the movement of the nodes of the core and the faces in perpendicular plane to the axis of the beam.

The FE analysis performed can be broadly classified into two parts: linear buckling analysis and nonlinear post-buckling analysis. The main purpose of the linear buckling analysis was to calculate critical load according to variable properties of the core and the faces. Further, the linear buckling mode shapes are required in specifying the imperfections needed to trigger post-buckling in the non-linear analysis.

The sandwich beam considered in the paper is simply supported at both ends and loaded with two equal bending moments N_f – couple of forces, placed symmetrically (Fig.1). It was assumed, that in critical load, the upper face buckles (wrinkling), while the lower face remains flat. The FE analysis was performed for 2D model.

Three-layered beam with length L = 400 mm and width b = 100 mm consists of two metal faces t_f = 0.4 mm (E_f = 210 000 MPa), and core t_c = 20 mm (E_c = 1000 MPa) (Fig. 1). In addition, in place of support of the beam, rigid membrane has been modelled in order to avoid local deformations caused by a point force (Fig.1). Poisson ratio and Young modulus of the membrane were as follows: ν_m = 0.3, $E_m = 2\cdot10^8$ MPa. PLANE 183 elements have been used to model

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the faces and the core of the beam. For the core and the faces modelling solid elements have been used.

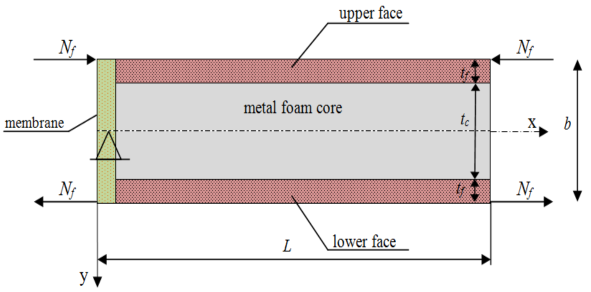
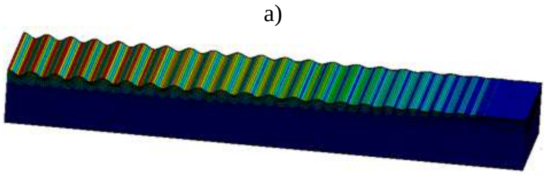


Figure 1: Schematic model of three-layered beam

3. Research results

Buckling modes obtained for linear and nonlinear analysis are presented in Fig. 2. For linear model, buckling mode has a shape of short waves. The largest value of the amplitude appears at the centre of the beam and decreases with increasing the distance from the plane of symmetry (wrinkling of the upper face is not uniform on the whole length of the beam). For nonlinear model, the amplitude of wavelength is more uniform than for linear one.

a)



b)

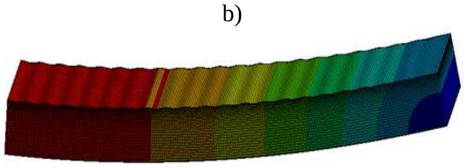


Figure 2: Buckling modes for: a) linear and b) non-linear characteristic of core material

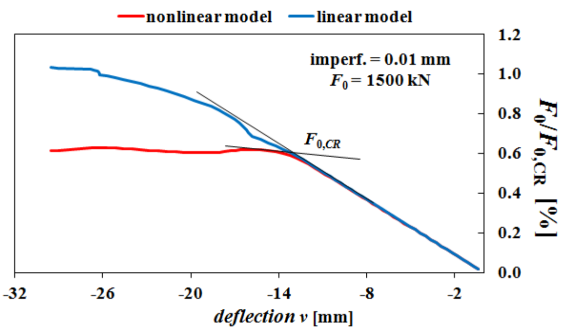


Figure 3: Deflection values of the beam for linear and nonlinear analysis

Deflection values for different material properties of the core are presented in Fig. 3. The value of the deflection, at the same load, was greater for nonlinear structure of the mechanical properties of the core.

The values of normal stress in the core and the faces are presented in Fig. 4 and 5. It can be shown, that these values are significantly different from each other, depending on the properties of the core material.

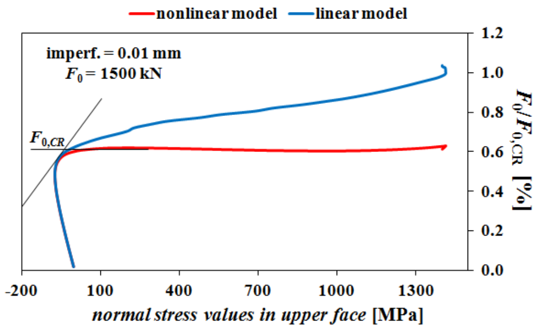


Figure 4: Normal stress values of the upper face

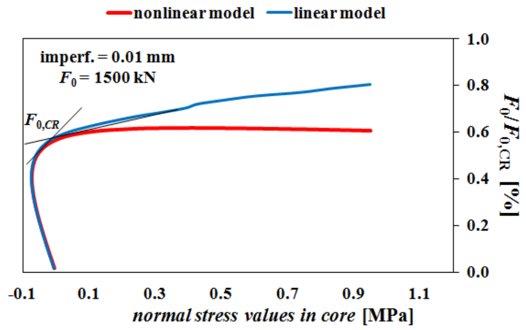


Figure 5: Normal stress values of the core

4. Conclusions

The main objective of this work was numerical analysis of stability of three-layered beams with metal foam core. Regardless of the material of the core and the faces, buckling mode for linear and nonlinear analysis was similar. The changes were related to critical load values. Post-buckling analysis allowed to estimate deflection of the beam and normal stress values. The value of the deflection, at the same load, was greater for nonlinear structure of the mechanical properties of the core. In addition, the analysis of the influence of geometrical imperfections on deflection and normal stress values was performed. It was concluded, that imperfections have significant influence on deflection values as well as normal stress values in faces and core. This work is the starting point to the further research, including the analytical ones, related to the analysis of local loss of stability of three-layered beams with metal foam core.

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