Deformation of the upper face of a sandwich beam under pure bending

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Abstract

In the present work the deformation of the face of a sandwich beam under pure bending is analysed. The 2D model of the beam has been modelled with the use of ANSYS code and the problem has been solved using finite element method. The results of numerical investigations on the buckling and post-buckling behaviour are presented. Two types of the material of the core has been analysed: linear elastic and non-linear. It is noted that the plastic properties of the core may influence the buckling load considerably and that they may also change the post-buckling behaviour. The later issue is especially important if a sandwich structure is used as a shock absorber and the way of its damage should be known or controlled.

Keywords: sandwich beam, buckling, stability, plastic deformation, non-linear analysis

1. Introduction

Analysis of the loss of stability of structural elements is usually conducted with the assumption that the phenomena has an elastic character. This approach is reasonable since in most cases if the structure fails due to buckling it is expected to returns to the initial configuration; thermal buckling of thin plates or shells can serves as an example. The plastic behaviour of the material usually has catastrophic results.

When the simplest case of a sandwich structure is considered there are two different materials which have to be taken into account – the material of the faces and the material of the core. The mechanical properties of these materials may be considerably different. This means that at the moment of buckling one of the material behaves plastically whereas the other one is still in an elastic range. Therefore the behaviour of one part of the sandwich structure, the core for example, may influence the behaviour of the other one, that is the face. Even though the buckling load for the linear and non-linear material of the core may be the same, the way in which the damage of both materials proceed may be different – that is the post-buckling behaviour can be different.

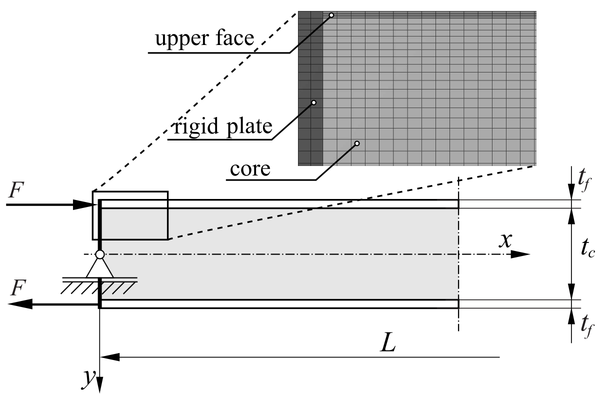

Figure 1: Model of the beam – dimensions, boundary conditions and finite elements layout

A typical buckling shape of a sandwich beam under pure bending is the wrinkling of the upper face. It has the form of short waves. Number of works has been published regarding wrinkling phenomena in which the results obtained with different models are presented. Finite element method has been used by Hadi [2]. Analytical model has been presented by Jasion and Magnucki [3, 4]. Buckling of sandwich columns with different properties of the material of the core has been analysed by Le Grognec and Sad Saoud [1]. Local buckling of sandwich beam with non-linear core has been investigated by Koissin *et al.* [5]. The results of experiments on post-buckling behaviour of wrinkled sandwich elements are presented by Mashadndi *et al.* [6].

The following sections concerns the local stability of a sandwich beam with a light core. The influence of the model of the material on the post-buckling behaviour of the upper face is analysed. A two dimensional model of the simply supported beam under pure bending is analysed.

2. Numerical model of the beam

The analyses have been performed in the ANSYS software. A two-dimensional model of the beam has been prepared using PLANE183 elements with 6 nodes and 2 degrees of freedom at each node. Due to the symmetry of the boundary conditions a half of the beam has been modelled. It was assumed that the buckling mode will be symmetrical as well. The geometrical parameters of the beam are: length $L = 400$ mm, width $b = 50$ mm, thickness of the faces $t_f = 0.3$ mm, thickness of the core $t_c = 20$ mm. To obtain a pure bending conditions a rigid plate has been attached to the end of the beam and a couple of forces was applied to the faces of the beam as shown in Fig. 1.

A non-uniform mesh has been generated with higher density near the upper face where the wrinkling phenomenon is expected. Between the layers of the beam as well as between the beam and the rigid plate bonding conditions have been applied. The beam is simply supported at the mid-hight of the rigid plate.

For the faces the linear elastic model of the material has been used with Young's modulus $E = 20000$ MPa. For the core $E = 50$ MPa. For both models Poisson's ratio $\nu = 0.3$. Since the influence of the plasticity of the core on the post-buckling behaviour of the beam is analysed plastic properties of the material has been ascribed according to Eq. (1)

$$\varepsilon = \frac{\sigma}{E}\left[1 + c\left(\frac{\sigma}{E}\right)^{2m}\right], \tag{1}$$

in which vales of the constants are $c = 3000$, $m = 1.4$. These constants can be estimated based on the static tensile test results. The stress-strain relation based on the above formula and for selected constants is shown in Fig. 2.

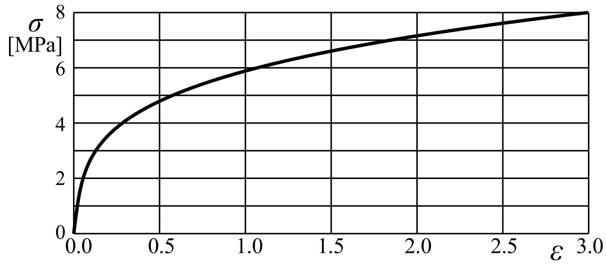

Figure 2: Model of the material of the core

3. Results of analyses

The investigation has been started with the linear buckling analysis in which the buckling shapes (see Fig. 3a) have been determined used further as a shape of imperfections in the nonlinear analysis. The buckling loads have been also determined used as a reference value in the post-buckling analyses. It is worth to notice that for the analysed case the sixth buckling load is higher from the first one only about 0.5% what suggests that in the post-buckling behaviour jumps from one mode shape to another are possible.

The post-buckling analysis has been performed whit the imperfection size equals about 0.5% of the face thickness. Results are shown in Fig. 3b in which the equilibrium paths for two different materials of the core, linear elastic and non-linear are presented. Vertical axis of the plot represents the bending moment applied to the beam (M) normalised by the moment corresponding to the loss of stability (M_{cr}). The horizontal axis gives the displacements divided by the thickness of the core.

The first significant difference is between the value of the buckling load. For the linear material the load is about 10% lower than this obtained in the linear analysis. For non-linear material the buckling load drops about 40%. The second difference is the behaviour of the beam in the post-buckling range. If the core has linear elastic properties the relation load-deformation is linear and the value of load increases with the increase of deflection. The deformation has the shape of short waves equally distributed on the upper face (Fig. 3c corresponding to point A in Fig. 3b). For the case of non-linear material the deformation of the beam increases but the load remains on the level of buckling load. The shape of deformation is also different since in the far post-buckling range a single wave forms in the mid-length of the beam (Fig. 3d corresponding to point B in Fig. 3b).

4. Conclusions

Based on the results presented in the previous chapter it can be seen that the character of the stress-strain relation for the material of the core influences considerably the post-buckling behaviour of a sandwich structures. On the one hand it means that when modelling such structures the mechanical properties of materials have to be chosen carefully. On the other hand the post-buckling behaviour can be controlled with the use of these properties.

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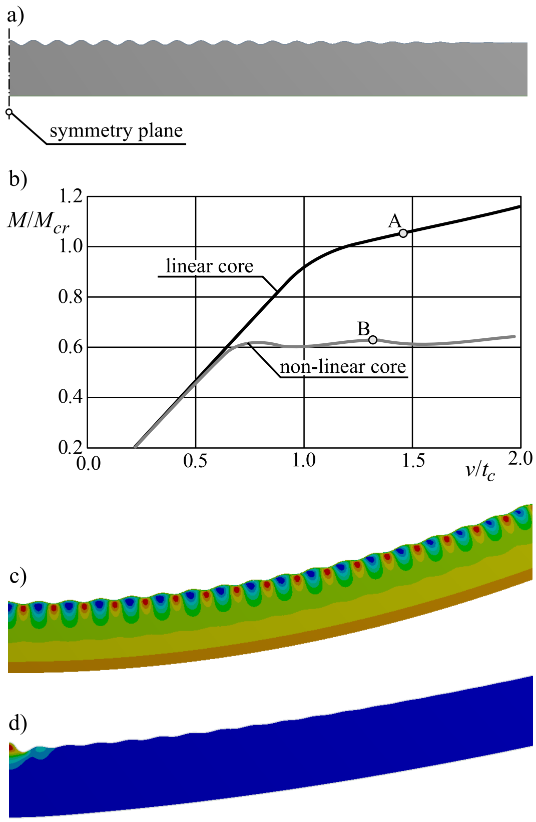

Figure 3: Results of buckling analysis: 1st buckling mode (a); equilibrium paths (b); modes of failure for linear (c) and nonlinear (d) core

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