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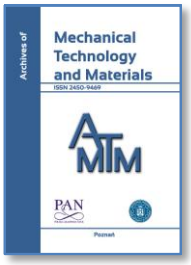

The influence of geometric imperfections on the stability of three-layer beams with foam core

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ABSTRACT

The main objective of this work is the numerical analysis (FE analysis) of stability of three-layer beams with metal foam core (alumina foam core). The beams were subjected to pure bending. The analysis of the local buckling was performed. Furthermore, the influence of geometric parameters of the beam and material properties of the core (linear and non-linear model) on critical loads values and buckling shape were also investigated. 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 geometric imperfections on deflection and normal stress values of the core and the faces has been evaluated.

1. INTRODUCTION

Multilayer structures appeared in the mid-twentieth century and, with them, the problem of their stability. They consist of two thin faces which are separated by the material of the core. The core is thicker and has lower density compared to the material of the faces. Nevertheless, the faces may differ in thickness values, material properties, or fiber orientation, or any combination of these three. Filler layer is required to sustain sufficient stiffness of the construction [12].

Most of sandwich structures have symmetrical construction. The core may be constructed of any material, but most commonly occurs in three forms: the honeycomb shape, corrugated core or foam core, e.g. polyurethane or alumina metal. The most significant property of the core is low density which results in low weight of the whole sandwich structure.

The most important advantages of using sandwich structures compared to traditional materials are: high stiffness to weight ratio, good buckling resistance compared to thin orthotropic plate structures and good crashworthiness properties. Furthermore, they are characterized by good dimensional accuracy and flatness [3].

Multilayer structures have also lots of disadvantages. They are susceptible to loss of stability (buckling), caused by thin-walled type of construction, and the occurrence of imperfections. Complicated mathematical model describing the loss of stability phenomenon enforces simplifications. In addition, there is no experimentally confirmed mathematical relationship describing the distribution of stress, strain and displacements of three-layer structures. They are also not resistant to concentrated loads and temperature changes [7].

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. This fact leads to specific design criteria for sandwich constructions [11].

Each construction, including three-layer constructions, regardless of their type; beams, plates, shells; are subjected to different loads. They become systems which are sensitive to their geometry, type of material, shape imperfections,

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character and intensity of loads as well as additional environmental factors. Their properties are strictly related to working conditions [8]. One of the most disadvantageous type of loss of stability of the construction is buckling. Buckling is characterized by a sudden sideways failure of a structural member subjected to loads, where the compressive stress at the point of failure is less than the ultimate compressive stress that the material is capable of withstanding.

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., plastic foam. For honeycomb or corrugated cores, this type of instability will not occur in practice, although local buckling of other types may occur. The wrinkling may be symmetric or asymmetric with respect to the center plane of the core and type of applied load [5].

The recent development of a number of cost-effective processes for making metallic foams has increased their potential for application in sandwich constructions for lightweight structural components, in energy absorption systems for protection from impacts, in heat sinks for electronic devices and in acoustic insulation. Metallic foams compete favourably with polymer foams as the lightweight cores of sandwich beams, plates and shells, due to the higher stiffness and high-temperature capability [2].

Traditional corresponding single-layer theories have been used by various of researchers for describing sandwich structures. However, the traditional corresponding single-layer theories such as classical, first-order shear-deformation may lead to erroneous results; e.g., when the core material is very soft [1, 4, 6, 8, 9, 10].

In this paper, the results of a numerical study of sandwich beam vulnerable to wrinkling are presented. The analysis was divided into two parts: linear buckling analysis and non-linear post-buckling analysis. First, a linear stability (buckling) analysis was performed to determine the critical loads values and extract the corresponding buckling modes. This was followed by a non-linear analysis in which imperfections in the form of buckling were incorporated. Post-buckling analysis allowed to measure deflection of the beam as well as strain values in the core and the faces.

2. MATERIAL MODELS

2.1. Linear elastic material model

First FE model is applied to linear elastic material of the core. One of the reasons for choosing such a model is the simplicity and uniqueness of the relationship between stress and strain. The fundamental "linearizing" assumptions of linear elasticity are: infinitesimal strain or "small" deformations (or strain) and linear relationships between the components of stress and strain.

The objective of the buckling problem is to estimate the maximum load value that a sandwich beam can sustain before loss of instability or buckling failure. The finite element analysis was used to estimate the linear buckling loads values and mode shapes of sandwich beams. The results from the linear buckling analysis are needed for the post-buckling (non-linear) analysis.

2.2. Non-linear elastic material model

In this model, the relationship between stress and deformation is described by a non-linear function. FE model is applied to non-linear elastic material of the core. For solution of the buckling problem, a geometrically non-linear analysis is generally applied.

Materials which exhibit plastic characteristics make many difficulties because of the fact, that the unload of the structure is conducted in a different way than the load. The buckling problem is also greatly simplified if the pre-buckling structural response is almost linear. In the majority of cases, commonly known kinematic hypothesis could be used (e.g. the hypothesis of flat sections).

3. FE MODEL

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 withdrawn from the core by half the thickness. The model was supported to block the movement of the nodes of the core and the faces perpendicular to the axis of the beam.

The FE analysis performed can be classified into two parts: linear buckling analysis and non-linear post-buckling analysis. The main purpose of the linear buckling analysis was to understand the effects of the core and the faces properties on the buckling load. Further, the linear buckling mode shapes are required in specifying the imperfections needed to start post-buckling analysis.

The sandwich beam considered in the paper is simply supported at both ends and loaded with two equal bending moments, generated by the couple of forcesN_f,placed symmetrically. The FE analysis was performed for 2D model.

Three-layer beam with length L = 400 mm and width b = 100 mm consists of two metal faces t_f = 0.4 mmand core t_c = 20 mm. Young modulus of the core and faces equals E_c= 50 MPa, E_f = 20 000 MPa, respectively.

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. Poisson ratio and Young modulus of the membrane were as follows: ν_m= 0.3, E_m= $2\cdot10^8$ MPa. For the core and the faces modelling solid elements have been used.The volume ratio of the material of the core relative to the whole construction is equal k = 1.019. The foam of the core has been modelled as regular particles on whole volume. PLANE 183 elements have been used to model the faces and the core of the beam. For FE model presented in this work 8-node element has been chosen.

4. RESULTS

4.1. Deflection, normal stress

Buckling modes obtained for linear and non-linear analysis are presented in Fig. 1. For linear model, buckling mode has a shape of short waves. The largest value of the amplitude appears in the center of the beam (upper face) and decreases with decreasing the distance from the support. For non-linear model, the amplitude of wavelength is more uniform than for linear one.

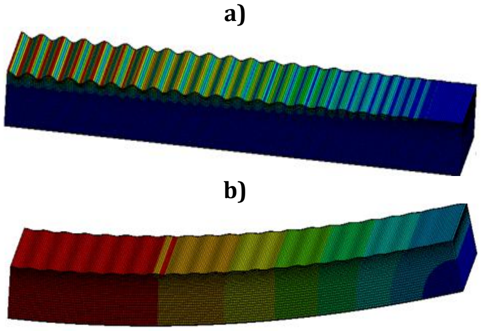

Fig. 1. Buckling modes for: a) linear and b) non-linear characteristic of core material

Deflection values for different material properties of the core are presented in Fig. 2. The value of the deflection, at the same load, was greater for non-linear structure of the mechanical properties of the core.

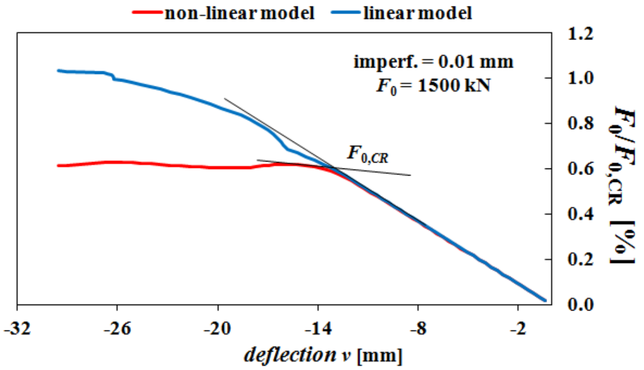

Fig. 2. Deflection values of the beam for linear and non-linear analysis (geometric imperfection values equal 0.01mm)

The values of normal stress in the core and the faces are presented in Fig. 3 and 4. It can be shown, that these values are significantly different from each other, depending on the properties of the core material. The values of normal stress were greater for non-linear structure of the mechanical properties of the core.

4.2. Geometric imperfections

Geometric imperfections are classified as the main cause of differences between analytical and experimental results. The influence of geometric imperfections on deflection values of three-layer beam subjected to pure bending is presented in Fig. 5. The imperfections were introduced into stability analysis by perturbing the initial geometry. The imperfections have direct influence on deflection values as well as normal stress values in faces and core. It was found that the imperfections did not remarkably reduce measured values of the sandwich beam, but they can cause the post-buckling behavior unstable.

Fig. 6 – 8 present the influence of geometric imperfections on deflection and normal stress values for variable material of the core. The different imperfection amplitudes were used to scale the amplitude of the modes. Face failure occurs before the core failure for all imperfection amplitudes and for both linear and non-linear core materials.

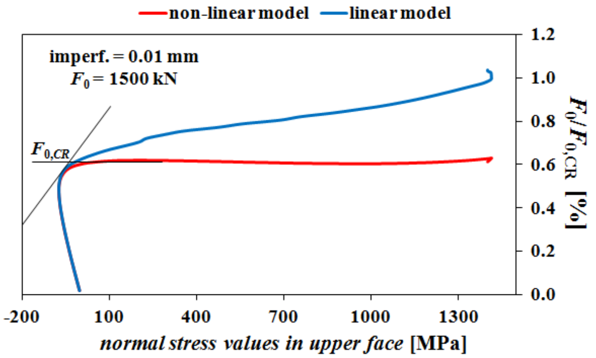

Fig. 3. Normal stress values of the upper face for linear and non-linear analysis (geometric imperfection values equal 0.01mm)

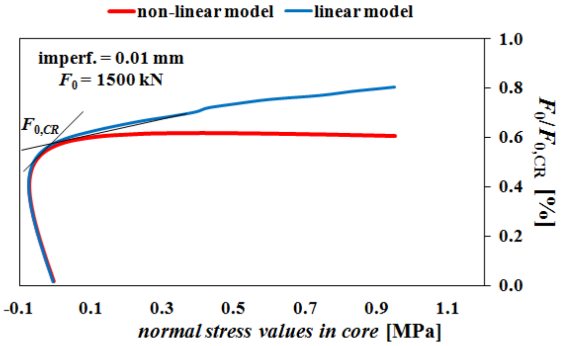

Fig. 4. Normal stress values of the core for linear and non-linear analysis (geometric imperfection values equal 0.01mm)

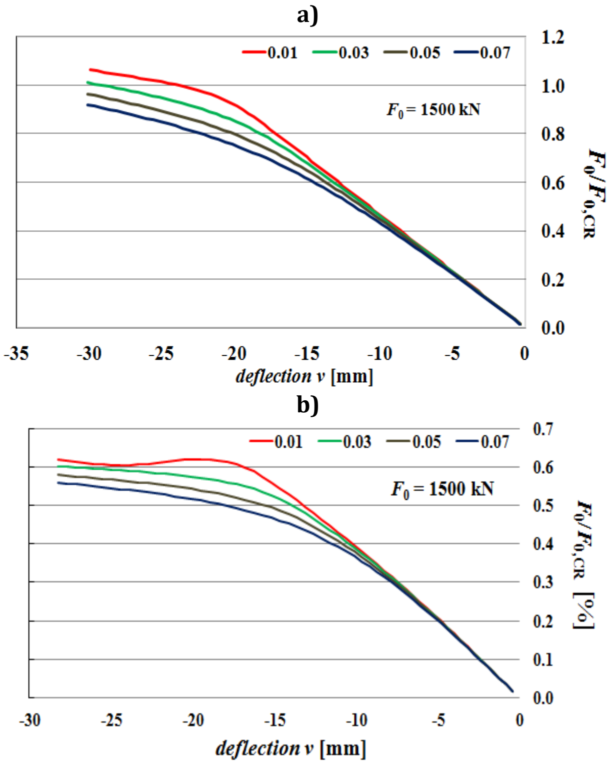

Fig. 5. The influence of geometric imperfections on deflection values: a) linear, b) nonlinear analysis

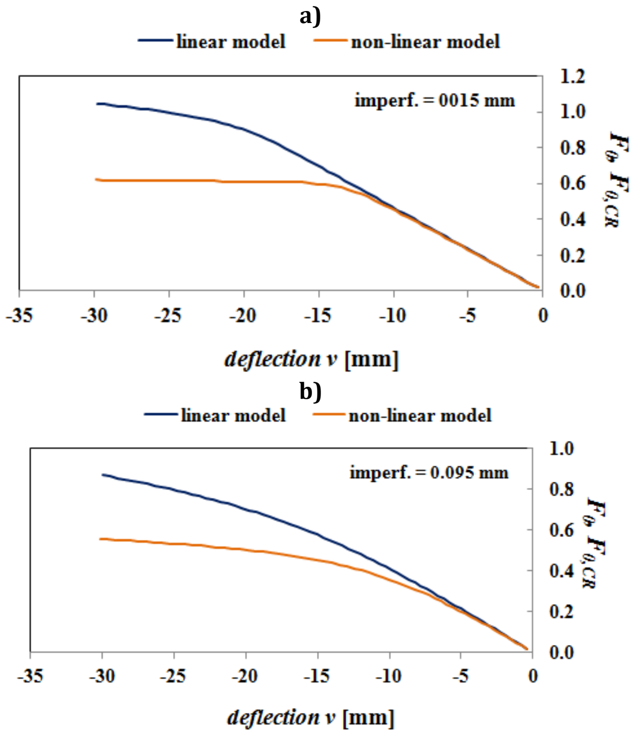

Fig. 6. Deflection values for different values of geometric imperfections: a) 0.015 mm, b) 0.095 mm

The geometric imperfections have been applied to the upper face.They were incorporated in the form of buckling modes.They mainly caused variance of dimension of the wave appeared when critical load is applied. Mode imperfections are given as the part of overall thickness of the beam, *t*, where $t = 2 \cdot t_f + t_c$ (0,1 imperfection corresponds to a maximum imperfection amplitude of 0.1 mm). The nonlinear analysis was conducted using the arc-length method, in which the axial load could increase or decrease while the arc length increases monotonically.

The used approach combines the stability analysis with a strength analysis, where the face compressive failure is the assumed failure mode. It was numerically confirmed that even with a completely symmetric model, the amplitude values of the face and the core stresses vary between the left and the right parts of the model. A small amplitude (with the values of imperfections equal 0.015 mm) reduces the strength of the beam to what may be anticipated assuming wrinkling instability as a failure mode. Larger amplitudes (e.g. 0.95 mm) reduce the load-bearing capacity, down to as much as 60% of the traditional wrinkling load.

Regardless of the material properties of the core and the faces, buckling mode is the same. Only critical load values change. Basic characteristics of the core mainly depend on the type of material used and also on the stiffness of the structure in perpendicular direction to the surface. The influence of the core material (linear and non-linear model) and the geometric imperfections have a significant impact on the values of deflection and normal stresses in the faces and core.

Analytical and numerical results often do not coincide. It is associated with the occurrence of geometric imperfections. Real beams are not perfectly straight and are usually associated with geometric imperfections that may affect their buckling behavior and strength. Generally, geometric imperfections can be divided into two categories; global imperfections and cross-sectional imperfections.

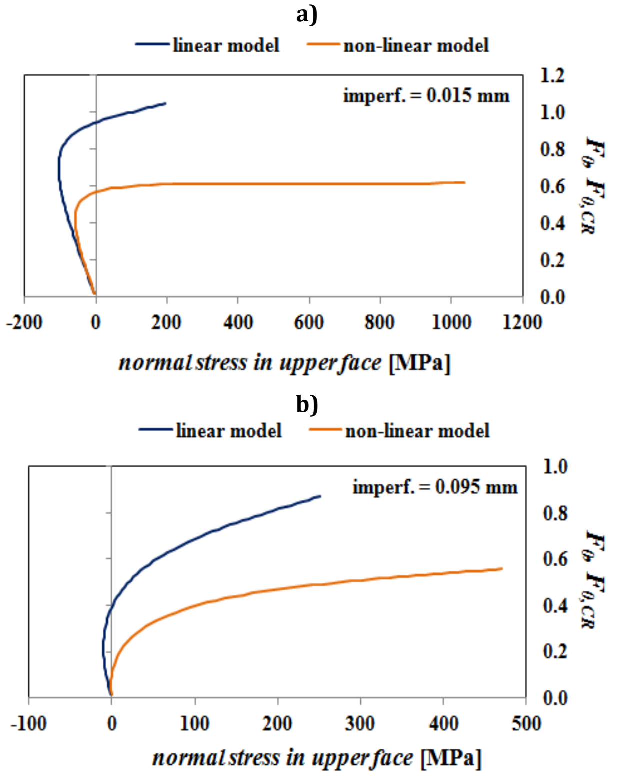

Fig. 7. Normal stress values of the upper face for different values of geometric imperfections: a) 0.015 mm, b) 0.095 mm

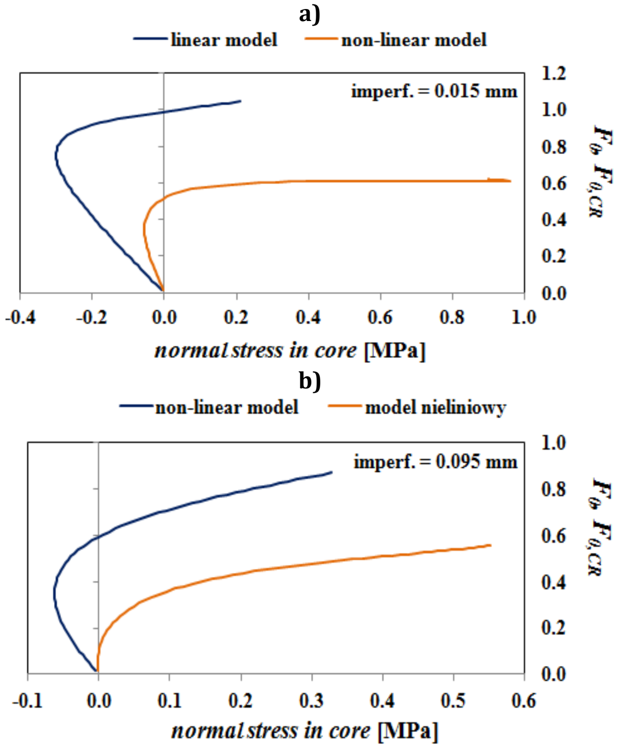

Fig. 8. Normal stress values of the core for different values of geometric imperfections: a) 0.015 mm, b) 0.095 mm

Random geometric imperfections are natural in many structures. They used to be ignored in strength analysis. In this work, geometric imperfections were included in the waveform given by linear stability analysis (sinusoidal wrinkling-buckling shape). These imperfections lead to increase displacements during loading so their impact on deflection and stress values in plastic range must be carefully examined.

5. CONCLUSIONS

The main objective of this work was the numerical analysis of stability of three-layer beams with metal foam core. The analysis was divided into two parts: linear buckling analysis and non-linear post-buckling analysis. Regardless of the material of core and faces, buckling mode for linear and non-linear properties of the core material was similar. The changes were related to critical load values. Post-buckling analysis allowed to estimate deflection and normal stress values. In addition, the analysis of the influence of geometric imperfections on deflection and normal stress values was performed. Imperfections were incorporated in the natural waveform given by the linear stability analysis, e.g., a short wavelength sinusoidal buckling shape. It was concluded, that imperfections have influence on deflection as well as normal stress values in faces and core.

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