ARCH. MECH. TECH. MATER.VOL. 39, (2019) 32-35

DE GRUYTER OPEN

ARCHIVES OF MECHANICAL TECHNOLOGY AND MATERIALS
WWW.AMTM.PUT.POZNAN.PL

Bending of an annular three-layer circular plate

Karolina Wiśniewska-Mleczko [a*]

[a] *Poznan University of Technology, Jana Pawła II 24 Street, 60-965 Poznan, Poland*

[*] *e-mail address: Karolina.sta.wisniewska@doctorate.put.poznan.pl*

ARTICLE INFO

Received 27 November 2017
Received in revised form 26 July 2019
Accepted 23 August 2019

ABSTRACT

The main objective of this work is the numerical analysis of the strength and stiffness of an annular three-layer circular plate with variable mechanical properties of the core. The plates are subjected to bending. Numerical analysis of the deflection phenomenon is carried out under different support conditions of the plate. Furthermore, the influence of the material properties of the core (linear and non-linear model) on the shear stresses and deflecions is also investigated.

KEY WORDS

annular three-layer circular plate, bending, FEM, shear stresses, deflections

1. INTRODUCTION

The problems of buckling of layered structures have been studied since the 1960s. When designing layered structures, strength and stability conditions are active constraints. Stability conditions include global buckling problems. Basic theory of sandwich structures is described in the literature [1-5]. Multilayer structures appeared in the mid-twentieth century and, with them, the problem of their stability. A special case of multilayer structures are sandwich structures. 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.

A 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 [6].

Contemporary works considering annular plates are by Pawlus [7-9]. These works present the stability of the core of an annular sandwich plate, as it is often analyzed. Pawlus presented the solution to the dynamic stability problem of the three-layered, annular plate with wavy, asymmetric forms of buckling. Analytical description of the phenomenon of buckling, as well as the results of numerical and experimental research on this subject is presented by Stiftinger and Rammerstorfer [6]. Luo and Teng [10] describe the deflection of a circular plate as a special case of coating on a Winkler foundation. Analytical and numerical analysis of layered circular plates are presented by Luo et al. [11].

Mechanical properties of aluminum foam under the shear load are described in Rakow and Waas [12]. The details about different models of displacements in the three-layer structure can be found in the work by Magnucka-Blandzi [13]. Strength and buckling problems of sandwich beams and rectangular plates with a metal foam core are described by Magnucka-Blandzi [14-15]. The application of nonlinear hypothesis is presented. The static stability problem of

DOI: 10.2478/amtm-2019-0006

sandwich annular plates with a soft core is analyzed in Pawlus [16]. Circular plates under blast load are analyzed by Radford et.al. [17] with the use of the finite element method.

The paper is devoted to an annular three-layer circular plate. The core has variable mechanical properties and is made of metal foam. Two cases are considered: simply supported plate and clamped plate. Moreover, the plate is supported on the outer or its inner edge. Numerical (FEM) analysis is conducted. The plate is loaded with the pressure applied to the upper face. The deflections and shear stresses in all support cases are calculated. The results of analyses are presented on figures showing the stress distribution and on plots showing the deflection of each point of the plate.

2. NUMERICAL MODELING (FE MODEL)

The finite element analysis has been prepared with the use of ANSYS software. Due to the symmetry of the presented model only a quarter of the plate has been modelled. On two symmetry planes the symmetry conditions have been set automatically. Tie constraints have been applied between the core and the faces. The upper and the lower faces have been drawn from the core by half of their thickness. Depending on the load condition, the displacements of the nodes of both core and the faces have a lock in the vertical direction – simply supported palate or in the vertical and radial direction – clamped plate. Circumferential displacements are limited due to symmetry conditions.

The annular three-layer circular plate (Fig.1) is considered in different cases:

- supported on the inside and the outside diameter,
- simply supported and clamped,
- with linear and nonlinear variable mechanical properties of the core.

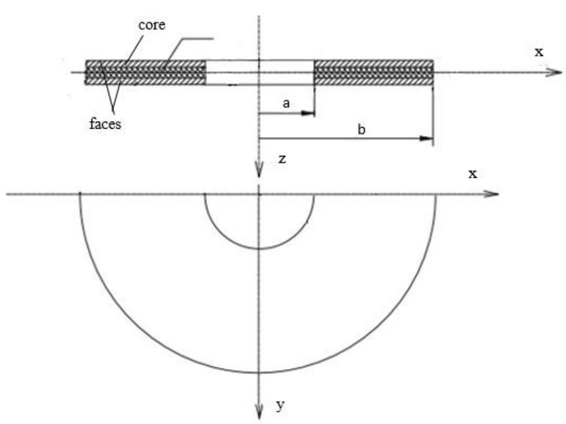

Fig. 1. Scheme of the plate

The FEM analysis was performed for 3D model. Three-layer plate has inside radius a=100mm and outside radius b=250mm. It consists of two metal faces of the thickness t_f=1mm and the core of the thickness t_c=18mm. Young modulus of the core and faces equals E_c=1200 MPa, E_f=12 000 MPa, respectively. Poison's ratio ν_c in the core is kept constant and equals 0.3. Fig. 2 shows the linear and non-linear characteristics of the foam material. It changes according to the formula 1. The nonlinear mechanical properties (Fig.2) of the core vary according to the relation (see Magnucki [18]):

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

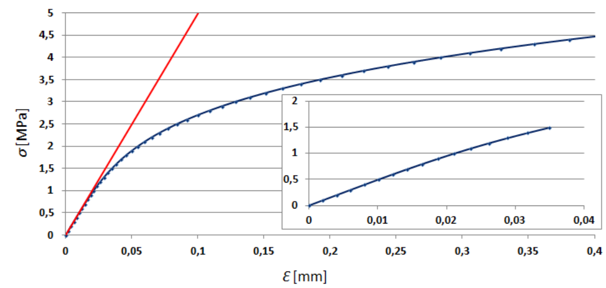

Fig. 2. Linear and nonlinear characteristics of foam material

where c and m are dimensionless constants the value of which was chosen to fit the curve to the experimental data.

The elements have been used to model the faces (shell 281) and the core (solid 186) of the plate. For FE model presented in this work 5 *mm* about size element has been chosen.

FEM SOLUTIONS

The numerical (FEM) analysis with the use of ANSYS system has been realized for data given in the previous paragraph.

The annular three-layer circular plate is subjected to pressure. All the cases considered are described above.

Shear stresses [MPa] calculated for the plate with linear and nonlinear material of the core are presented in Figures 3–10. The cases for the plate supported at the inner edge are presented in Figures 3–6, whereas for outer edge are presented in Figures 7–10. It could be observed that the difference between maximum values of shear stresses for linear core material (different types of support) is 19 % (Figures 3, 4), whereas for nonlinear core material the values of shear stresses are close to zero (Figures 5, 6). Taking into account the plate supported at the outer edge it is observed that the difference between maximum values of shear stresses for linear core material (different types of support) is 117 % (Figures 7, 8), whereas for nonlinear core material the discrepancies between maximum values are 34% (Figures 9, 10).

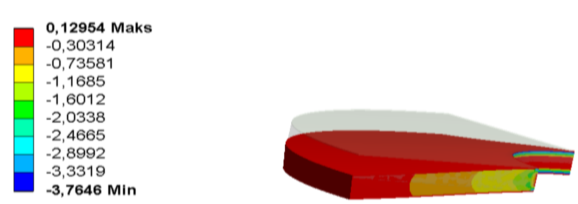

Fig. 3. Shear stress, linear core material – inner edge simply supported

Fig. 4. Shear stress, linear core material – inner edge clamped

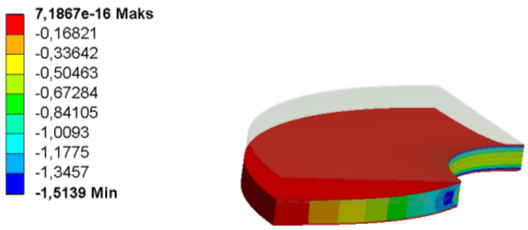

Fig. 5. Shear stress, nonlinear core material – inner edge simply supported

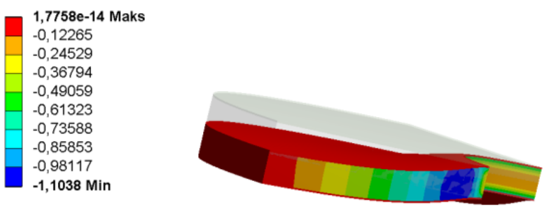

Fig. 6. Shear stress, nonlinear core material – inner edge clamped

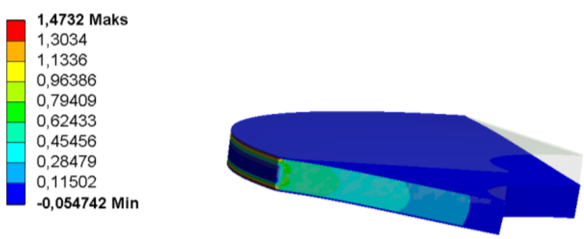

Fig. 7. Shear stress, linear core material – outer edge simply supported

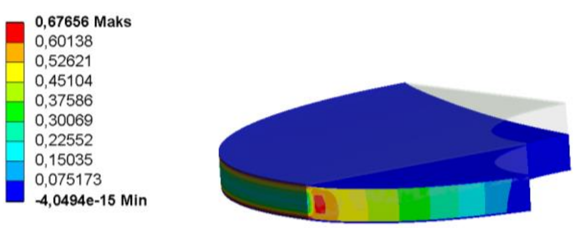

Fig. 8. Shear stress, linear core material – outer edge clamped

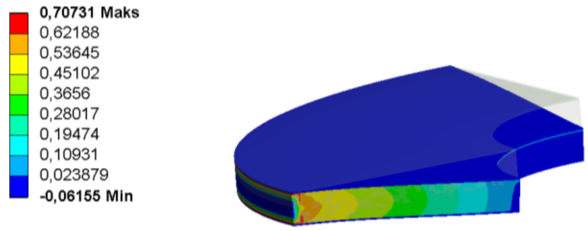

Fig. 9. Shear stress, nonlinear core material – outer edge simply supported

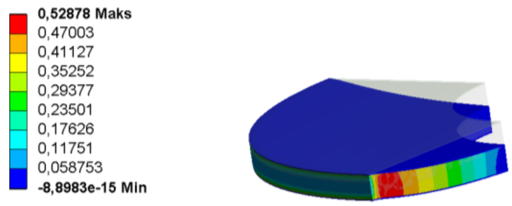

Fig. 10. Shear stress, nonlinear core material – outer edge clamped

The comparison of the deflections were also realized for each case. The influence of the mechanical properties of the plate core to deflections is presented in Figures 11–14. The Figures 11 and 12 are devoted to the plate with inner supported edge, whereas the Figures 13, 14 to the plate with outer supported edge. Linear and nonlinear characteristics of deflections are presented. In each case the deflections are bigger for nonlinear material of the plate core then for the linear material. The deflections for the plate with inner supported edge are bigger than the deflections for the plate with outer supported edge. The difference is about 185% and 169 % for simply supported plate and for clamped plate, respectively.

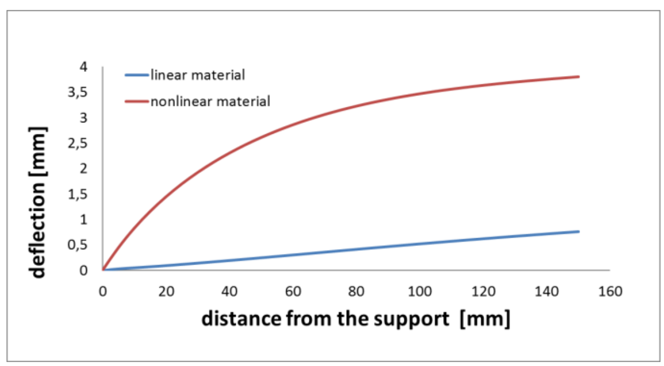

Fig. 11. Linear and nonlinear deflection characteristics, simply supported inner edge

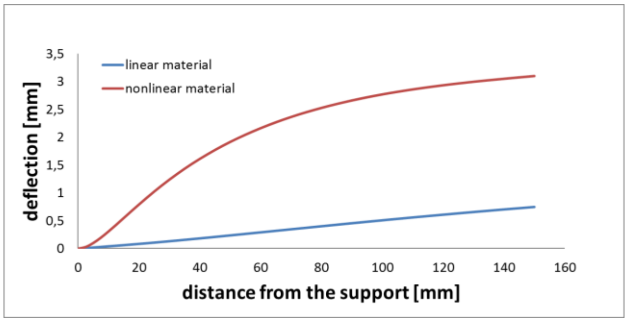

Fig. 12. Linear and nonlinear deflection characteristics, clamped inner edge

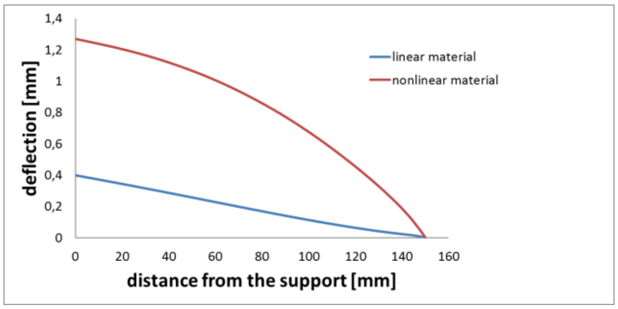

Fig. 13. Linear and nonlinear deflection characteristics, simply supported outer edge

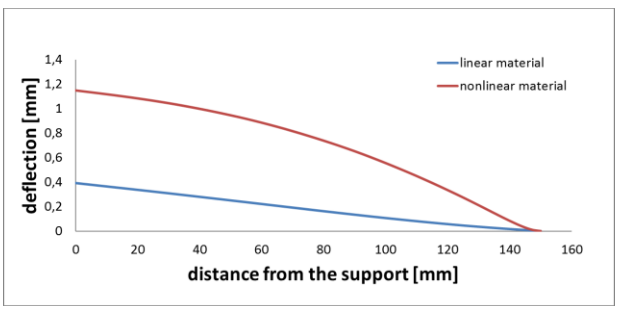

Fig. 14. Linear and nonlinear deflection characteristics, clamped outer edge

3. CONCLUSIONS

The main objective of this work was the numerical analysis of bending of an annular three-layer plates with metal foam core. It could be stated that

- larger deflection values were obtained for the nonlinear characteristics of the core material,
- the support conditions of the plate with nonlinear foam core have a significant influence on the results – the plate deflection,
- greater values of stresses were obtained for the plate with outer supported edge,
- the greater values of the shear stresses are for linear materials.

ACKNOWLEDGEMENTS

Presented research results, carried out by the statutory activities DSMK, were founded by grants for education (02/21/DSMK/3481) by the Ministry of Science and Higher Education.

REFERENCES

[1] **Libove C., Butdorf SB.,** A general small-deflection theory for flat sandwich plates. NACA TN 1526 (1948).
[2] **Reissner E**., Finite deflections of sandwich plates. Journal of the Aeronautical Science;15(7) (1948) 435–40.
[3] **Plantema FJ.,** Sandwich construction: the bending and buckling of sandwich beams, plates and shells. New York: John Wiley and Sons, (1966).
[4] **Allen HG.,** Analysis and design of structural sandwich panels. Oxford: Perga- mon Press, (1969).
[5] **Vinson J. R.,** Sandwich structures, American Society of Mechanical Engineers, 54(3) (2001) 201-214.
[6] **Stiftinger M.A., Rammerstorfer F.G.,** Face Layer Wrinkling in Sandwich Shells – Theoretical and Experimental Investigation, Thin-Walled Structured, 29 (1997) 113-127.
[7] **Pawlus D.,** Solution to the static stability problem of three-layered annular plates with a soft core, Journal of Theoretical and Applied Mechanics 44(2) (2006) 299–322.
[8] **Pawlus D.,** Approach to evaluation of critical static loads of annular three- layered plates with various core thickness, Journal of Theoretical and Applied Mechanics, 46 (1) (2008) 85–107.
[9] **Pawlus D.,** Stateczność dynamiczna trójwarstwowych płyt pierścieniowych z rdzeniem lepko sprężystym, Rozprawy Naukowe Z. 399, Łódź (2010).
[10] **Luo Y.F., Teng J.G.,** Stability analysis of shells of revolution on nonlinear elastic foundations, Computers and structures, 69 (1998) 499–511.
[11] **Luo J.Z., Liu T.G., Zhang T.,** Three-dimensional linear analysis for composite axially symmetrical circular plates, International Journal of Solids and Structures, 41(3) (2004) 689–706.
[12] **Rakow J.F., Waas A.M.,** Size effects and the shear response of aluminum foam, Mechanics of Materials , 37 (2005) 69–82.
[13] **Magnucka-Blandzi E.,** Mathematical modelling of a rectangular sandwich plate with a metal foam core, Journal of Theoretical and Applied Mechanics, 49(2) (2011) 439–55.
[14] **Magnucka-Blandzi E., Magnucki K.,** Effective design of a sandwich beam with a metal foam core. Thin-Walled Structures (2007);45:432–8.
[15] **Magnucka-Blandzi E.,** Non-linear hypotheses of deformation of flat cross sections of elastic sandwich beam, Applied Mathematics and Mechanics, 9 (2007) 703–714.
[16] **Pawlus D.,** Approach to evaluation of critical static loads of annular three- layered plates with various core thickness. Journal of Theoretical and Applied Mechanics, 46(1) (2008) 85–107.
[17] **Radford D.D., et al.,** The response of clamped sandwich plates with metallic foam cores to simulated blast loading, International Journal of Solids and Structures, 43(7– 8) (2006) 2243–59.
[18] **Magnucki K., Szyc W.,** Wytrzymałość materiałów w zadaniach; Pręty, płyty I powłoki obrotowe, Wydawnictwo Naukowe PWN, Warszawa, Poznań 2000