OPTIMAL DESIGN OF AXIALLY COMPRESSED SANDWICH COMPOSITE CYLINDERS HAVING ORTHOGRID CORE

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ABSTRACT

This study is concerned with the structural analysis and optimal design of sandwich composite cylinders having ortho-grid core and frp skin. The related stability problems are numerically solved using a degenerated shell finite element model. First, equivalent extensional, bending, and shear stiffnesses for the proposed configuration are obtained. Then, optimal designs are obtained for some selected geometries and material properties using a simple graphical optimization method.

Keywords: sandwich, orthogrid, equivalent stiffness, cylinder, finite element method.

EKSENEL BASINÇ ALTINDAKİ DİK-IZGARA ÇEKİRDEKLİ KOMPOZİT SANDVİÇ SİLİNDİRLERİN OPTİMUM TASARIMI

ÖZET

Bu çalışmada, eksenel basınç altındaki dik-ızgara çekirdekli ve frp dış yüzlü kompozit silindirlerin yapısal analiz ve optimum tasarımları üzerinde durulmuştur. İlgili stabilite problemleri dejenere bir kabuk sonlu elemanlar modeli kullanılarak çözülmüştür. Öncelikle, eşdeğer eksenel, eğilme ve kayma rijitlikleri belirlenmiştir. Daha sonra basit bir grafik optimizasyon yöntemi kullanılarak seçilen geometri ve malzeme özellikleri için optimum tasarımlar elde edilmiştir.

Anahtar Kelimeler: sandviç, dik-ızgara, eşdeğer rijitlik, silindir, sonlu elemanlar yöntemi.

1. INTRODUCTION

This study is concerned with the structural analysis and optimal design of sandwich composite cylinders having ortho-grid core and frp skin.

Kassapoglou (2013) has examined the effect of the core on increasing the bending stiffness of a sandwich composite plate and reported that even very small core thicknesses may result in a thousand fold increase of the bending stiffness. This improvement will cause a very small increase in total weight. The core will be under a state of nearly pure shear stress for sandwich panels under transverse loads and for these structures rigid plastic foam (xps, pur) is generally used as the core material. However, the core sections of axially compressed sandwich cylinders may fail due to crushing under axial compression, seperation from the skin, or shear

crimping. Therefore, the core sections of sandwich composite cylinders should be stiffer and a simple solution to this problem is to use a framed or lattice core.

Anisogrid lattice (AGL) cylinders are reported to be one of the most efficient structural configurations for axial compressive loading; see Vasiliev *et al*. (2001). It is also reported by Vasiliev *et al* (2001) that AGL structures are less sensitive to imperfections. However, production of AGL structures may be time consuming and costly due to their complicated geometry. Considering these problems, Han and Tsai (2003) have developed a relatively simple manufacturing method for a square grid using slotted joint and adhesive bonding with pultruded ribs. A similar interlocking type grid structure was also considered by Jiang *et al*. (2017). Li *et al*. (2018) have designed and tested a composite cylinder having the same geometry but corrugated core. The same geometry is selected in the present study, in order to be able to make comparison.

The numerical results obtained are presented in comparison with the results found in the literature and the optimal design parameters are determined fort he selected geometry and loading.

2. PROBLEM STATEMENT

The following dimensions are selected for the both ends clamped cylinder: The outer diameter, $2r$=625 mm and length L=392.7 mm. The skin thickness is also taken as constant, i.e. equal to 2 mm. The circumferential ribs are slotted at every 22.5°, i.e. the total number of axial members is 16. The distance between the circumferential ribs is taken as equal to L/N, where N is an integer.

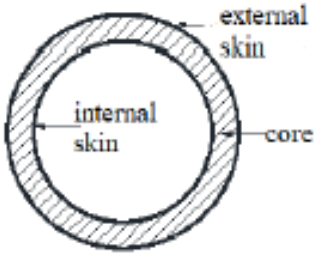


Figure 1. The cross-section of the sandwich composite cylinder

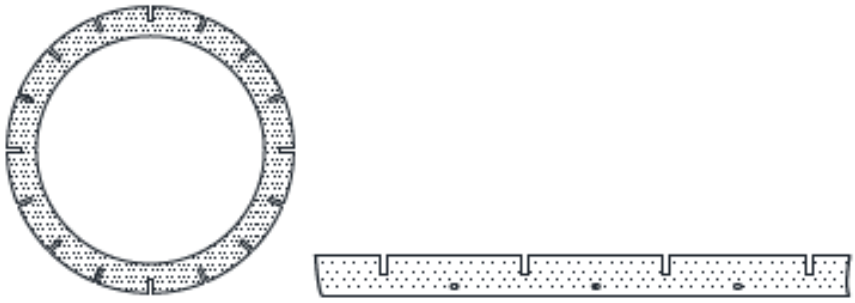


Figure 2. (a) Slotted ring (b) Slotted stringer

Kim (1999), Fan et al. (2009), Jiang et al. (2017) and Li et al. (2018) have selected the same diameter and very

similar cylinder length values and have presented numerical and experimental results for composite cylider designs. The highest failure loads and total weights presented by Kim (1999), Fan et al. (2009), Jiang et al. (2017), and Li et al. (2018) were 116.9 kN (3.24 kg), 524.6 kN (3.8 kg), 302.75 kN (4.6 kg), and 491.7 kN (4.7 kg), respectively.

3. ANALYSIS AND DESIGN-ANALİZ VE TASARIM

An 8-noded super-parametric/degenerated shell element is used for structural analysis; see Cagdas and Adali (2013). The following assumptions are made;

1. Local buckling of the ribs is assumed to be prevented.
2. It is assumed that the structure fails due to buckling not due to excessive stress.
3. There is perfect bond between the skin and the ribs.

3.1. Homogenization

The core stiffness is calculated by using a homogenization approach; see Cagdas (2010). The rib heights and widths are denoted by h_0, h_{90} and b_0, b_{90}, respectively. Here subscripts 0 and 90 denote the axial and circumferential ribs, respectively. Accordingly, the non-zero entries of the 3×3 **D** matrix (flexural stiffness) for the grid core are given below;

$$D_{11}^{grid} = \left(\frac{EI_0}{d_0}\right),\ D_{12}^{grid} = D_{21}^{grid} = 0,\ D_{22}^{grid} = \left(\frac{EI_{90}}{d_{90}}\right),\ D_{33}^{grid} = \frac{1}{4}\left(\frac{GJ_0}{d_0}\right) + \frac{1}{4}\left(\frac{GJ_{90}}{d_{90}}\right) \quad (1)$$

where, EI_0, EI_{90}, and G denote the out of plane bending rigidities of the 0°, 90° ribs, and shear modulus, respectively. Similarly, GJ_0, GJ_{90} are the torsional rigidities of the 0°, and 90° ribs, respectively. d_0, and d_{90} denote the distances between the 0°, and 90° ribs, respectively.

The non-zero entries of the 2×2 **C** matrix (shear stiffness) for the grid core are given below;

$$C_{11}^{grid} = \kappa\left(\frac{GA_0}{d_0}\right),\ C_{22}^{grid} = \kappa\left(\frac{GA_{90}}{d_{90}}\right) \quad (2)$$

where, GA_0, GA_{90} denote the shear rigidities of the 0°, 90° ribs, respectively. Note that, the shear correction factor, κ, is taken as equal to 5/6.

The non-zero entries of the 3×3 **A** matrix for the grid are given below;

$$A_{11} = \left(\frac{EA_0}{d_0}\right),\ A_{12} = A_{21} = 0,\ A_{22} = \left(\frac{EA_{90}}{d_{90}}\right),\ A_{33} = 0 \quad (3)$$

where, EA_0, EA_{90} denote the axial rigidities of the 0°, 90° ribs, respectively.

The resultant stiffness matrices of the grid with skin are obtained by superposition as given below;

$$\boldsymbol{A} = \boldsymbol{A}^{skin} + \boldsymbol{A}^{grid}$$

$$\boldsymbol{C} = \boldsymbol{C}^{skin} + \boldsymbol{C}^{grid}$$

$$\boldsymbol{D} = \boldsymbol{D}^{skin} + \boldsymbol{D}^{grid}. \qquad (4)$$

Note that, the bending-extension coupling matrix **B**=[0] due to symmetry. The stiffness coefficients for the ribs are calculated by using the following equations;

$$\overline{EA} = btE_{11}; \overline{EI} = \frac{1}{12}(bt^3E_{11}) ; \overline{GA} = \frac{5}{6}btG_{12} ; \overline{GJ} = \frac{1}{3}bt^3G_{12}.$$

3.2. Material Properties:

It is assumed that the skin and the ribs are made up of a unidirectional composite material having density of 1.27 g/cm^3. The following material properties are taken for the skin and the ribs.

E_{11}=11395 MPa; E_{22}=1200 MPa; ν_{12}=0.3; G_{12}=524 MPa; G_{23}=450 MPa; G_{13}=524 MPa.

Here direction 1 coincides with the lengthwise coordinate.

3.3. Preliminary Numerical Results

1st design (SCC-1): Numerical results for a sandwich composite cylinder having a rigid foam core having 10 mm thickness are obtained for comparison purpose. The following mechanical properties are taken for the foam core;

E_{core}=10 MPa, G_{core}=5 MPa, ν_{core}=0.2;

For this case, the buckling load is calculated as equal to 126.857 kN and the buckling mode shape is shown below in Fig. 3. The total weight of the 1st design is approximately equal to 5.8 kg for foam density equal to 250 kg/m^3.

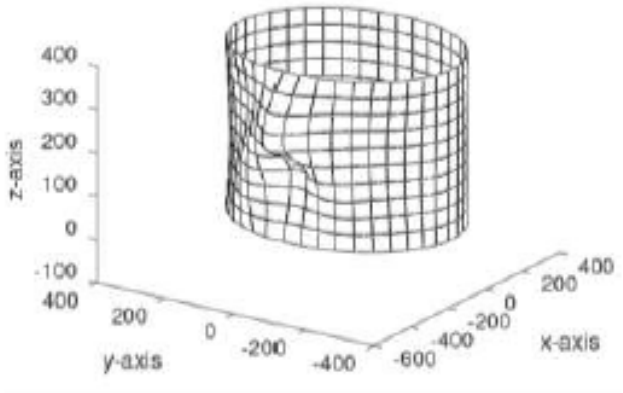


Figure 3. Buckling mode shape for SCC-1.

2nd design (SCC-2):

The following values are selected for the grid members:

$h_0 = h_{90}$=10 mm, and $b_0 = b_{90}$=2 mm.

For N=8, the total weight W= 4.45 kg and the buckling load P_{cr}= 133.458 kN. This initial result shows that the grid core does not significantly increase the buckling load for $h_0 = h_{90}$=10 mm. It is also determined that increasing N has insignificant influence on the buckling load.

3.4.Parametric Study

Considering the initial numerical results, it is decided to increase the rib height and to determine the level of increase in the buckling load. The results obtained are presented in Table 1 and the buckling mode shape for h_c=25 mm is shown in Fig.4. It can be observed from Fig. 4 that the buckling mode shape is localized. The results presented in Table 1 show that increasing the core thickness (or rib height) considerably increases the buckling load.

Table 1. The influence of core thickness on the buckling load.

$h_0 = h_{90}$ (mm)	W (kg)	Pcr (kN)
15	4.72	175.177
20	4.98	202.536
25	5.24	222.111

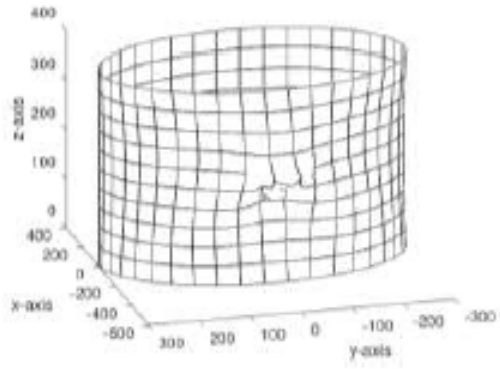


Figure 4. Buckling mode shape for h_c=25 mm.

CONCLUSIONS-NETİCELER

Structural analysis and optimal design of sandwich composite cylinders having ortho-grid core and frp skin is studied. Both skin and stiffening ribs (rings and stringers) are selected to be made of a unidirectional composite material having relatively low modulus.

The preliminary numerical results obtained show that rigid plastic foam may be a good alternative core material. However, an ortho-grid core is selected in this study due to the disadvantages of rigid foam material like creep behavior, water absorption, and high degree of anisotropy.

The numerical results obtained for the selected material properties and geometry show that increasing the rib height or core thickness may considerably increase the buckling loads for sandwich composite cylinders having ortho-grid core.

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