Non-linear buckling response of unstiffened laminated composite cylinders using different geometric imperfections

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Abstract

The important role of geometric imperfections on the decrease of the buckling load for thin-walled cylinders had been recognized already by the first authors investigating the theoretical approaches on this topic. However, there are currently no closed-form solutions to take imperfections into account already during the early design phases. Since 1970s a considerable number of experimental and numerical investigations have been conducted to develop new stochastic and deterministic methods for calculating less conservative KDFs. Among the deterministic approaches many suggest the use of different geometric imperfection patterns in order to investigate the imperfection sensitivity but there is no consensus about which imperfection pattern is the correct one. The present study will investigate the effect of five different imperfection patterns on the non-linear buckling response of unstiffened laminated cylinders with the aim to bring about general directives that can be used as future reference.

1 Imperfection patterns

In order to compare the different imperfection patterns a common parameter has been chosen: the imperfection amplitude ξ, which will determine how deep the imperfection is and therefore can be used to evaluate the imperfection sensitivity of the structures herein studies. The next sub-sections will present each imperfection pattern in more details. A full discussion about the results is available in Ref. [1] and will be discussed in the presentation during the conference.

1.1 Single perturbation load imperfection (SPLI)

A single perturbation load imperfection (SPLI) results in a local disturbance in the side of the cylinder. In particular, a cross-sectional view of the shell-wall displacements are shown in Fig. 1 and indicates the formation of multiple half-waves around the circumference (Fig. $1-a$) and one half-wave along the meridian of the cylinder (Fig. $1-b$).

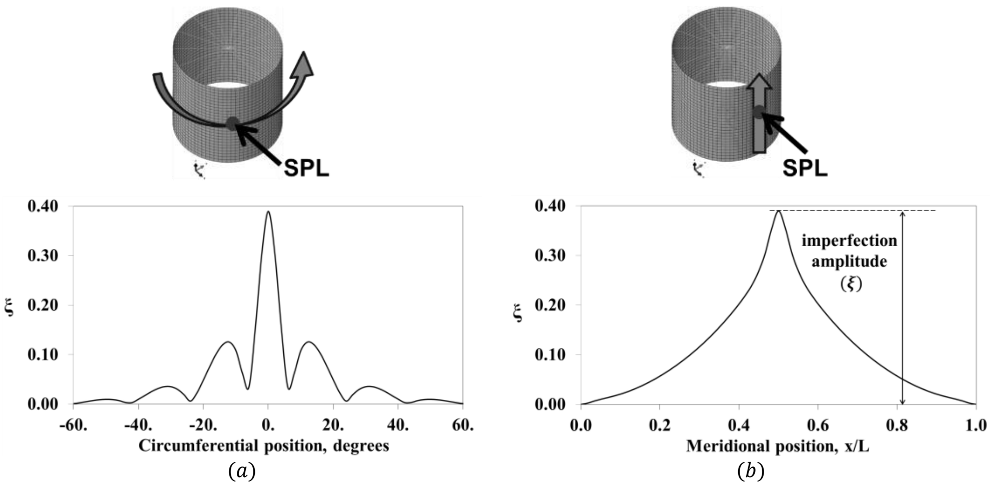

Fig. 1: Imperfection pattern for a SPLI, modified from Castro et al. [1]

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1.2 Geometric dimple-shaped imperfection (GDI)

The proposed model for the geometric dimple imperfection (GDI) was taken from Wullschleger, 2002 [2], shown in Fig. 2. The imperfection consists on a cosine dimple with two wavelengths defined, one along the circumference (a), another along the meridian (b). This type of cosine dimples is well known for axisymmetric imperfections (see for example Tennyson, Muggeridge and Hutchinson in [3] and [4], and Khamlichi et al. in [5]). Eq. (1.1) shows the radial displacement applied for the nodes belonging to the dimple imperfection. It is important to emphasize that a dimple created using this method is stress-free, since only the nodal position is being changed.

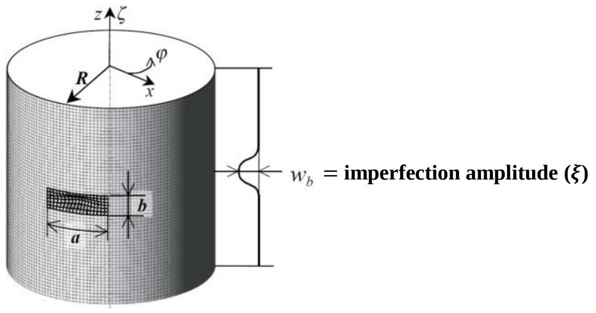


Fig. 2: Imperfection pattern for a GDI (modified from Wullschleger [2])

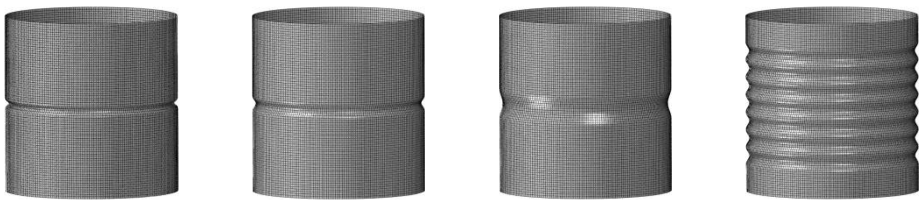
$$\Delta R(\varphi,\zeta) = \frac{w_b}{4}\left[1-\cos\left(\frac{2\pi R}{a}\varphi\right)\right]\left[1-\cos\left(\frac{2\pi}{b}\zeta\right)\right] \quad \text{with:} 0 \le \varphi \le a/R \text{ and } 0 \le \zeta \le b \tag{1.1}$$

1.3 Axisymmetric imperfections (ASI)

The implementation of axisymmetric imperfections can be done using a similar procedure already described for the dimple imperfections. The main difference is that only the meridional wavelength b is necessary, simplifying Eq. (1.1) to the cosine shape function that was first introduced by Tennyson & Muggeridge (1969) [3] for axisymmetric imperfections:

$$\Delta R(\varphi,\zeta) = \frac{w_b}{2}\left[1-\cos\left(\frac{2\pi}{b}\zeta\right)\right] \quad \text{with: } 0 \le \zeta \le b \tag{1.2}$$

As shown in Fig. 3, four different configurations for axisymmetric imperfections where used. The ASI 01 was designed to evaluate the effect of a sharper axisymmetric imperfection and ASI 04 was designed to be compared with the linear buckling modes showing a circumferentially oriented pattern. Patterns ASI 02 and 03 were designed to provide a comparison with the dimple imperfection patterns herein selected, as detailed in Castro et al. [1].

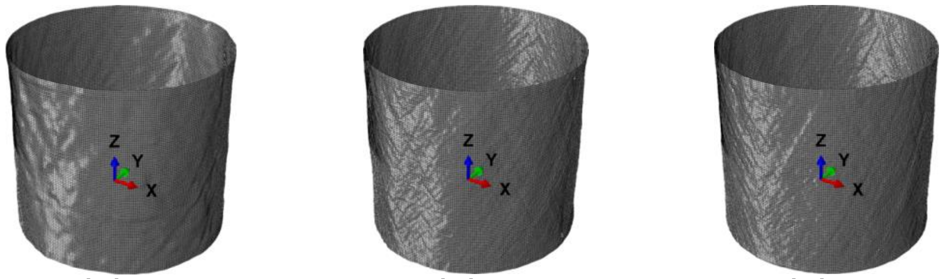


ASI 01, $b = 30mm$ position: *x/L* = 0.5	ASI 02, $b = 45mm$ position: *x/L* = 0.5	ASI 03, $b = 90mm$ position: *x/L* = 0.5	ASI 04, $b = 50mm$ positions:*x/L* = [0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8]

Fig. 3: ASI shapes used in the studies, copied from Castro et al. [1]

1.4 Mid-surface imperfections (MSI)

Degenhardt et al., 2008 [6] presented measured geometric imperfections for 10 laminated composite cylinders. Three measured imperfections: Z22, Z23, and Z25; were selected and used as initial imperfections in this study. From Table 1 it can be seen their measured thicknesses (the nominal thickness is 0.5 mm) and the imperfection amplitudes for a scaling factor $SF = 1$. The corresponding imperfection measurements are shown as deformed geometries in Fig. 4.



cylinder Z22 cylinder Z23 cylinder Z25

Fig. 4: Measured geometric imperfection patterns (scale = 50x), copied from Castro et al. [1]

Table 1: Measured imperfections extracted from Degenhardt et al. [6]

Cylinder	Z22	Z23	Z25
Thickness (mm)	0.486	0.478	0.468
Amplitude ξ (mm)	0.63145	0.70747	0.63169
Number of measured points	189740	341099	340357

For the three MSIs different scaling factors SF where applied to simulate variations in the manufacturing quality. Table 2 shows the different amplitude / laminate thickness (ξ/t) that were considered. The scaling factors necessary to achieve them were obtained with: $SF = (\xi/t)_{aimed} \cdot t_{laminate}/\xi_{MSI}$.

Table 2: Amplitude / laminate thickness (ξ/t) used for the MSIs

0.10	0.25	0.50	1.00	1.50	2.00	3.00	4.00	5.00	6.00

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3 References

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