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Research Paper

Effect of a crack emanating from notch on a composite pipe subjected to buckling

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ABSTRACT

New pipelines made with composite materials have to be well-designed for better mechanical performances. Recommendations for sizing stratified pipes have been proposed for different combinations of loads. In this context, our paper focus on buckling on laminated composite pipes, using numerical simulation. As a first part, we study free-defect pipes buckling for different pipe diameters, wall thicknesses and fibers orientation. In a second part, we evaluate the influence of defects (notches and crack due to notches), their parameters (size, orientation) and mechanical constraints (pipe under pressure, boundary conditions) on the structure. Results show a strong dependence of the size of the notch to the stability of the structure, amplified by the fibers orientation. Thus, for fibers oriented at an angle close to 20°, pipes manufacturing under these conditions show a particular strength of the structure. The crack length (independently on its orientation) seems to have no significant effect on the buckling factor and therefore the structure integrity, for transverse-orientated fibers and while their orientation go beyond 40°. The main variations are observed when fibers orientation is in the range from a few degrees up to 40°. Results are and discussed according the orientation of crack and fibers.

NOMENCLATURE

α	Inclination of the crack
θ	Stack angle
λ	Buckling coefficient
a	Dimension of notch
d	Composite pipe line diameter
e	Composite pipe line thickness

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E	Elastic modulus of carbon/epoxy material
G_{13}, G_{13}, G_{23}	Shear modulus of carbon/epoxy material
U_1, U_2, U_3	Imposed displacement
v_{12}	Poisson ratio

1 Introduction

Composite materials have interesting characteristics compared to traditional materials. They have many functional advantages like lightness, mechanical strength and chemical resistance, also allowing increasing the time life of some equipment with respect to mechanical and chemical properties.

Parts with complex shapes can be manufacturing while keeping a limited online maintenance. They generally present good thermal insulation and, for some of them a good electrical insulation. [1]

A composite material is composed of at least two components, and their combination gives a result with mechanical properties superior to those of the components taken individually [2-4]. They have become potential substitutions for conventional materials and are well suited for industrial fields such as aeronautics and aerospace where structures requiring lightness, strength and stiffness.

Introduced belatedly in the end of the 19th century, the buckling phenomenon is now an essential parameter to be taken into account for designing modern structures, often consist of thin shells as fuselage (aeronautics), hull underwater (shipbuilding) or special roofs (Civil Engineering). Last decades, the scientific community has sought to understand and predict the complex mechanics behaviour of structures [5] and their thermal behaviour [6]. Thus, the engineers in charge of designing these structures have now powerful simulation tools based on the theory of nonlinear finite element [7, 8]. Beside the loading type and the geometry of the structure, the choice of material is a fundamental element, which has to be taken in consideration. Characteristics of the chosen material play a primordial role in the behaviour of the structure, allowing a functioning in elastic buckling condition instead of a plastic one [9]. A great interest is being paid to the effect of applied loading; simple (compression [10, 11], bending [12], and external pressure [13] and combined load [14, 15]; as numerous studies have focused on the influence of the imperfection effect on material behaviour (Crack [16], perforation [17]...etc.). Buckling occurs due to compression forces that can come from several sources such as the direct effect of an external load, or the axial compression [18, 19].

2 Models and mesh layered pipe without Notches

For our application, a laminate composite pipe diameter d = 800mm with 10 layers alternating stratification has been chosen. The choice of the stack, and more particularly guidance will have specific mechanical properties [8], the stacking sequence is $[\theta^\circ/-\theta^\circ]_5$, each has a thickness of 0.176 mm. The pipeline has an overall length of 3000mm. The chosen material is carbon / epoxy, T700 /E, where its mechanical properties are given in Table 1.

Table 1 - Mechanical material properties of the pipe (T700 / E)

Properties	(T700/E)
E1(MPa)	143120
E2(MPa)	6672
ν12	0.26
G12(MPa)	3390
G13(MPa)	3390
G23(MPa)	1914

To determine the reliability of the design of this structure, with respect to the buckling, the variability of several parameters must be considered, three cases are identified. In the first time, the buckling behavior of compressed pipe is analysed. An internal pressure of 10 MPa was then added and in the third case, a combination with internal pressure of 10

MPa and 14 MPa external for compressed pipe are investigated. Figure 5 illustrates the three cases. One of the ends of the pipes is fixed, while the other end is subjected to an imposed displacement (Figure1). Our structure has been modeled by 9625 quadrilateral elements of type S8R. Three-point Gaussian registered integration has been considered,

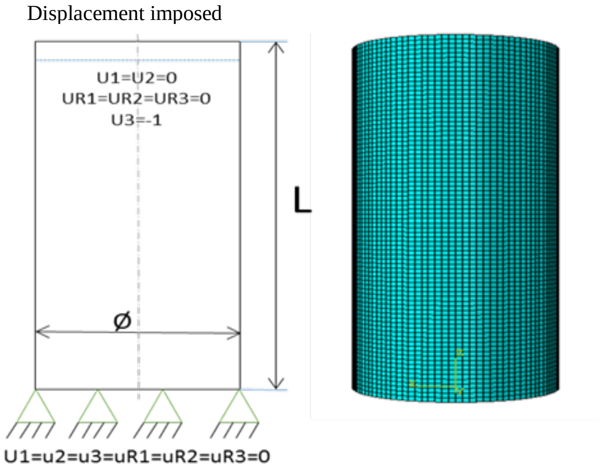


Fig.1–Representation of the boundary conditions and mesh pipeline unnotched

3 Evolution of the buckling coefficient for pipelines without notches

The evolution of buckling load factor λ is studied, depending on the the fibers orientation under the effect of an imposed displacement U3=-1mm for a perfect pipe (without geometrical defects), the obtained results were translated by the following curves.

3.1 Effect of pipe diameter

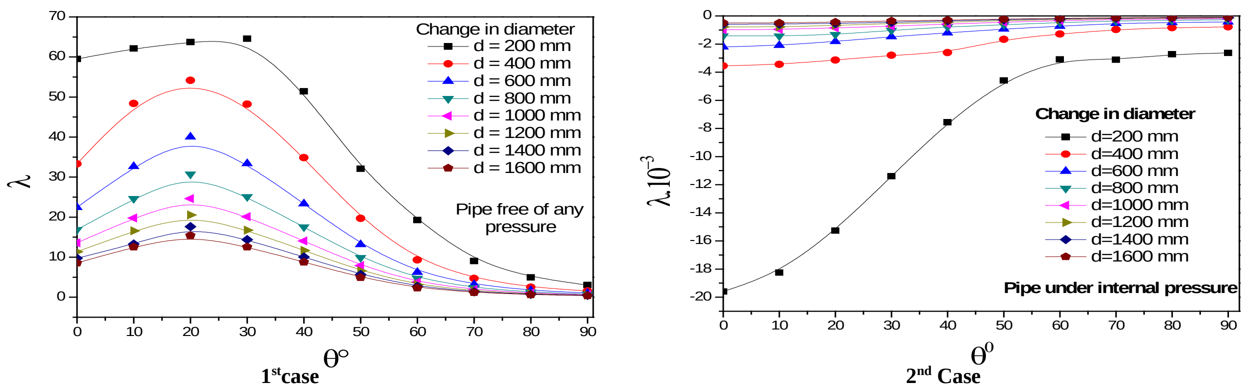


Fig. 2–Influence of the variation of the diameter of the pipe-buckling coefficient depending on θ

The figure 2 (first case) shows the evolution of the buckling factor λ according to the orientation of the composite fibers, for different pipe diameters. We notice that the buckling coefficient reached maximum and important values, when the fibers are oriented in an interval varying from 10° to 30°. The lowest values are obtained when the orientation of the fibers is between 60° and 90°.

In the second case, an internal pressure of 10 MPa was applied along the pipe, a new phenomenon has been discovered and λ factor took a negative value and that for all tests with internal pressure. We also note that the pipes with small diameters have some instability compared to other, therefore when the radius is bigger, the buckling is less important.

3.2 Effect of pipe thickness

Figure 3 shows the variation of the buckling coefficient in function of the fiber orientation for different values of the thickness of the pipe. The representation is done for four different thicknesses, e = 2mm, 4 mm, 6 mm and 8 mm and a diameter of 800 mm.

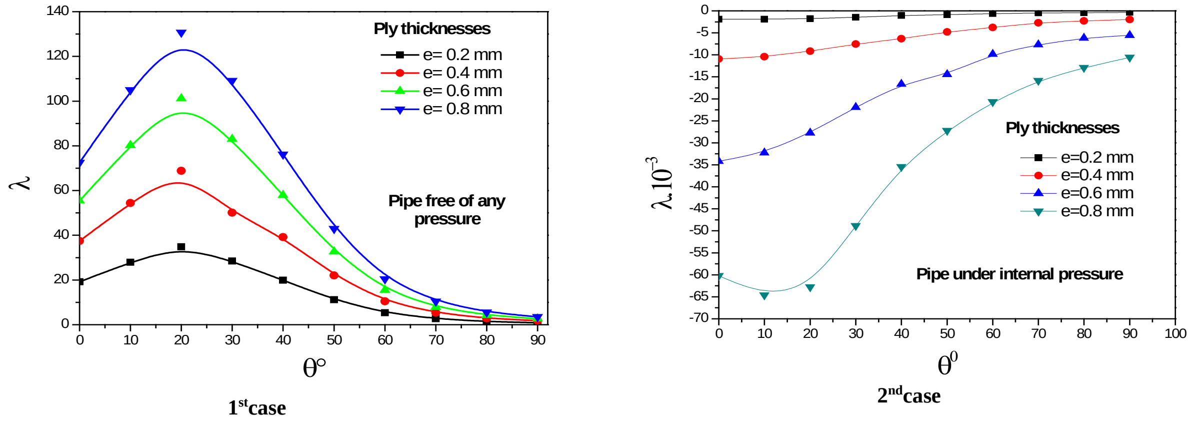


Fig. 3–Influence of the variation of the thicknesses of the pipe on the buckling coefficient in function of θ°

The buckling ratio in the first case is maximum for the 20° fiber orientation. Furthermore, when the angle θ exceeds 70°, the values of the critical load is almost constant. For the second case, an internal pressure of 10 MPa is exerted. Even earlier finding that, although we see λ takes negative values and are highest between 10° and 20° orientation.

Comparing the two figures, it can be noticed a difference in the values of buckling ratio, for a large thickness of the pipe, the ratio λ is greater. This means that the more the thickness of the pipe is greater the more it is stronger.

3.3 Effect of imposed displacements

In this case, the displacement-imposed effect was studied, as illustrated in Figure 4. four values have been the subject of our simulation, U1 = -1 mm - 5 mm, -10 mm and -100 mm, it is seen although more Fixture, the more the pipe is unstable, buckling coefficient is maximum 20° to the orientation of the fibers and become almost linear from the stacking sequence (60° / -60°). For pipe with internal pressure, λ takes negative and very small values, we see that the imposed displacement, for this case, has no significant effect.

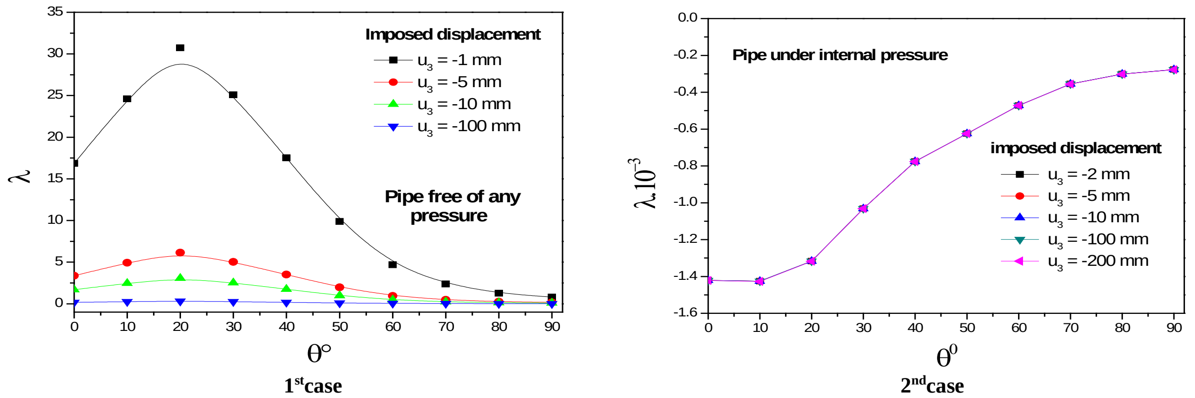
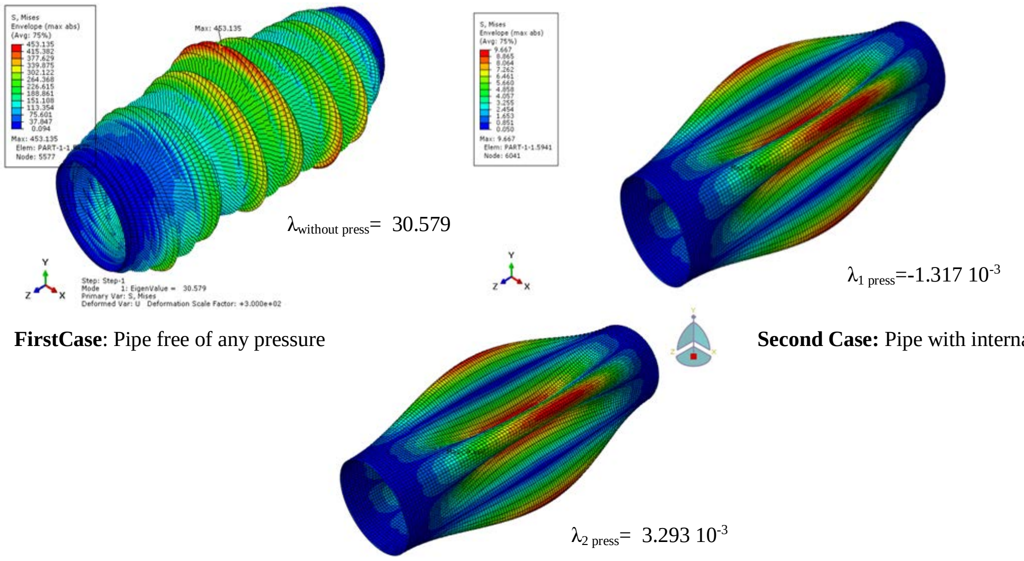


Fig. 4–Influence of variation in restraints on the buckling ratio depending on θ°

Figure 5 shows the effect of buckling for three cases, it's noticed that the buckling parameter is greater in the case where the pipe is depressurized.



FirstCase: Pipe free of any pressure

Second Case: Pipe with internal pressure

Third case: Pipe with internal and external pressure

Fig. 5–Effect of buckling on the pipes without notch

4 Evolution of the buckling parameter for pipes with notches

In this section, we consider a pipe length L = 3000 mm and diameter d = 800mm. The thickness of each pipe plies is set at e = 0.176mm.

Geometrical defects are provided in the form of single, and dual, square notches.

4.1 Critical buckling load for a pipe with a single notch

The pipes are encased in one end, the other is subjected to an imposed displacement U3 = - 1 mm.In the calculation, we used quadrilateral elements with a refined and structured grid near the notch as shown in Figure 6.

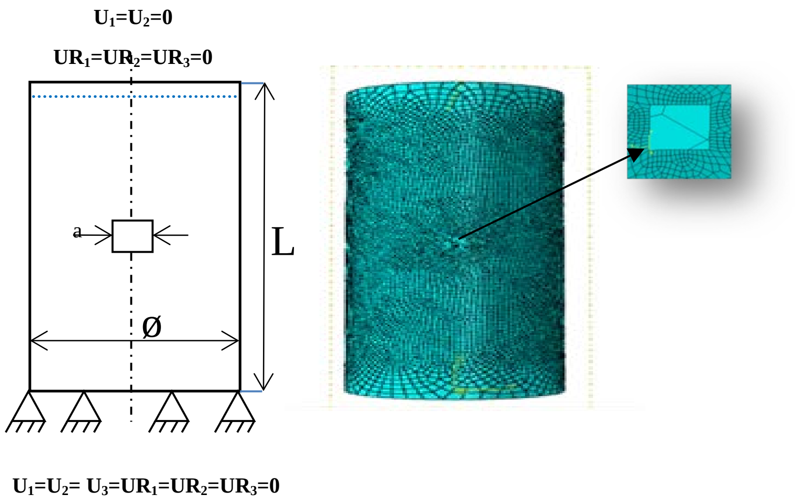


Fig. 6–Representation of boundary conditions and the pipeline with a square mesh notch

Figure 7 illustrates the variation of the buckling coefficient in function of the fiber orientation for different notches. The parameter λ is maximum when the angle of inclination of the fibers is oriented 20° in the majority of cases studied, the size of the notch is varied, a = 6mm, 10, 16, 20 and 40 mm, as shown in Fig 5. We also note that as the default size is greater the more the structure is low, against the second and third cases, the size of the cut has no effect on the buckling of the pipe.

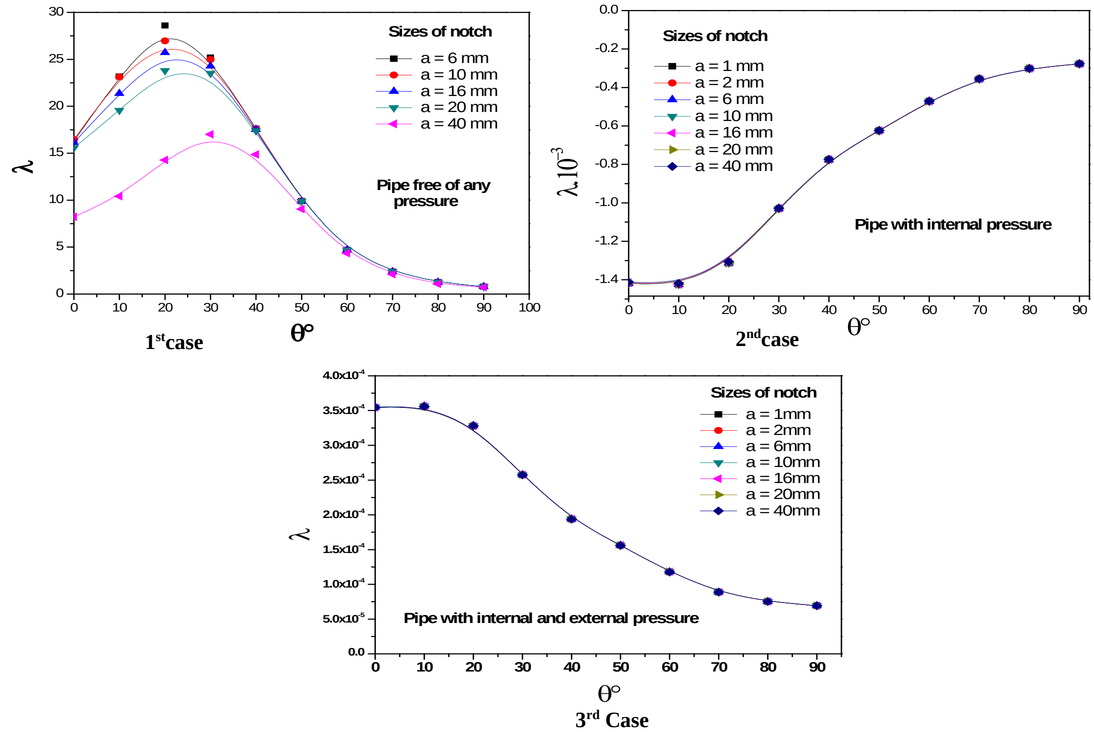


Fig. 7–Influence of size of the notch on the buckling factor as a function of θ°, for a pipe provided with a single notch

4.2 Critical buckling load for a pipe with two notches

The next part consists in two notches, one in the middle of the pipe, and the other with the same dimensions, located just next to underrun, as shown in (Figure 8). The presentation was made to two dimensions of notches, a = 10 mm and a = 16 mm

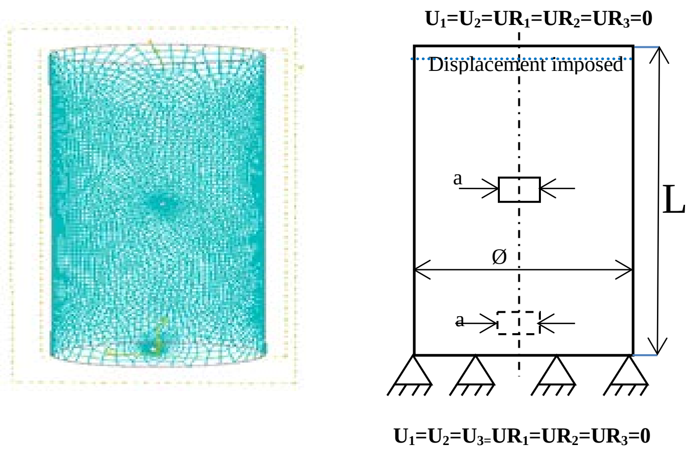


Fig. 8–Representation of the boundary conditions and pipe mesh with two square notch

The pipe with internal pressure is unstable, with low and negative parameters λ and reach a maximum value in the stack (10° / -10°) of λ = -1.418, by cons if we put additional external pressure the pipe, the maximum values of the parameter λ again become positive but lower than in the first case (λ = 3.5).

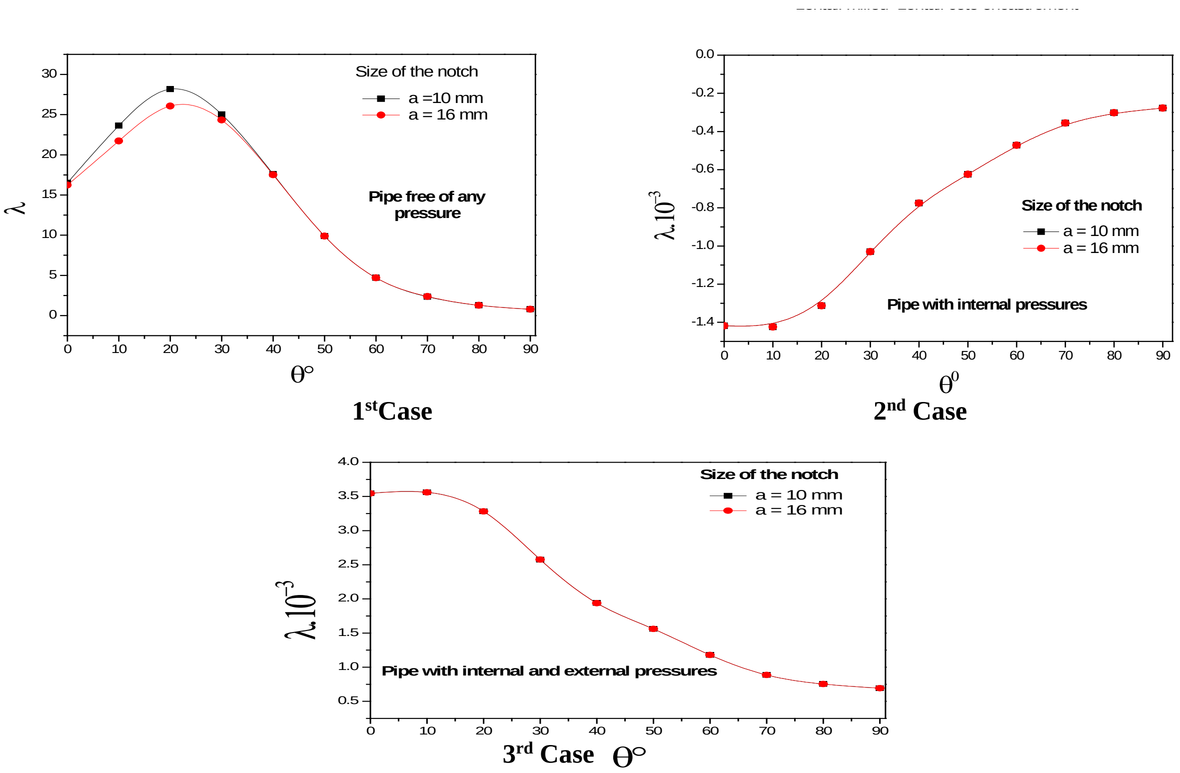


Fig. 9–Influence of size of the notch on the buckling factor as a function of θ°, for a pipe provided with dual, square notches

5 Critical buckling load for a pipe with a crack-emanating notch

5.1 Effect of longitudinal crack on the buckling parameter

To see the effect that can cause a longitudinal crack emanating a square notch on the structure under the effect of buckling (Figure 10), a study was conducted. For this, two sizes of the cut, a = 10 mm and a = 16 mm, have been doing our research. The size of the crack was varied as follows: l = 2 mm, l = 4 mm, 6 mm and l = 8 mm for each notch. The pipe in question is subject to the same boundary conditions as before. The total structure is discretized by a quadratic mesh. Three-point Gaussian integration per ply are considered.

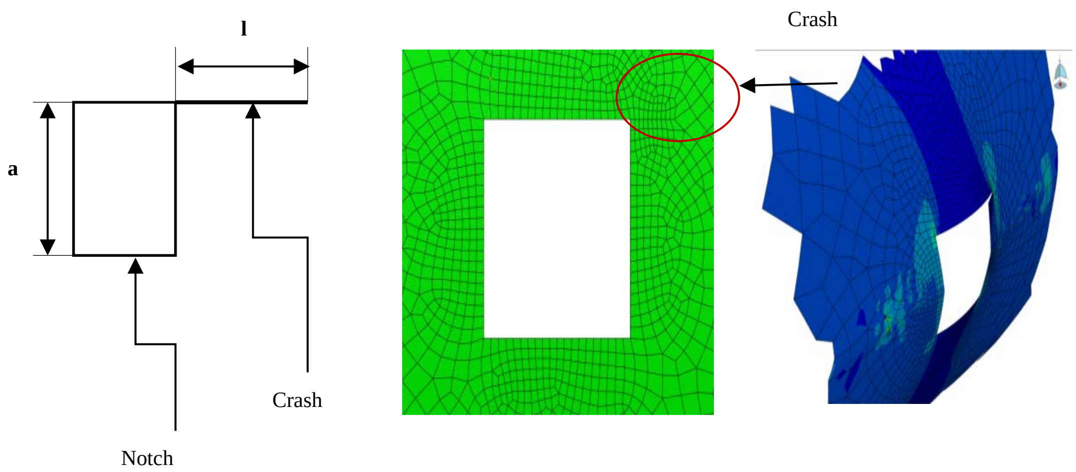


Fig. 10–The pattern and mesh at the notch and the longitudinal crack

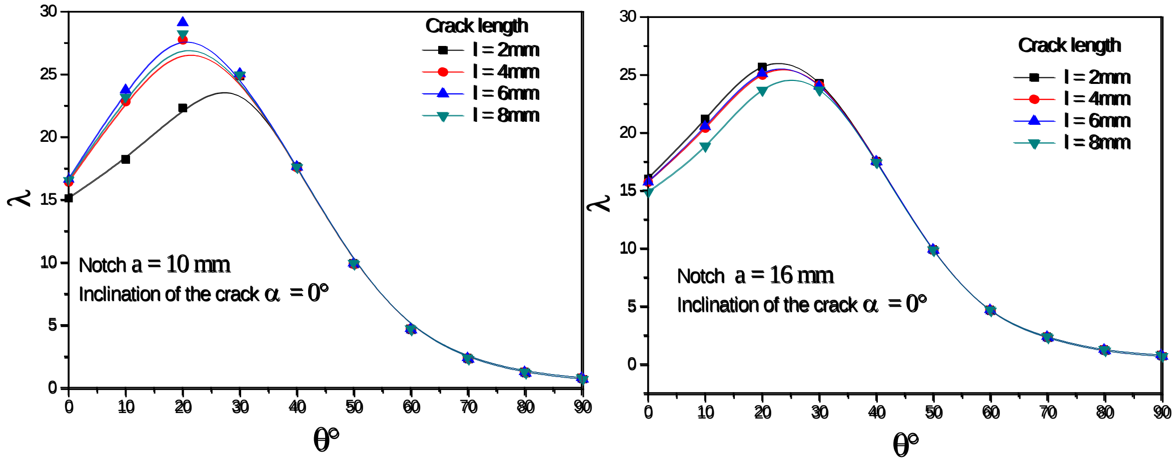


Fig. 11–Buckling parameter variation depending on the direction of the folds for a longitudinal crack

Figure 11 shows the variation in buckling factor depending on the orientation of the folds, for various lengths of cracks. The maximum values are obtained in the interval orientations of 10° to 30° from this orientation the factor of buckling decreases rapidly and we note that from this stacking sequence, the size of the crack has no significant effect on the buckling factor, and the smaller values of λ are between the stack $\theta = 70°$ and $\theta = 90°$.

We also note that for the smallest notches, $\lambda = 29.25$ contrary for the larger λ decreases slightly and reaches a value of $\lambda = 26$ of buckling. So we conclude that the size of the cut plays an important role in the stability of the structure. We also note that it is strongly affected when the orientation is 20°.

Figure 12 shows the effect of buckling that can cause a crack emanating from notch; we note that the most affected area is the one with the geometric defect.

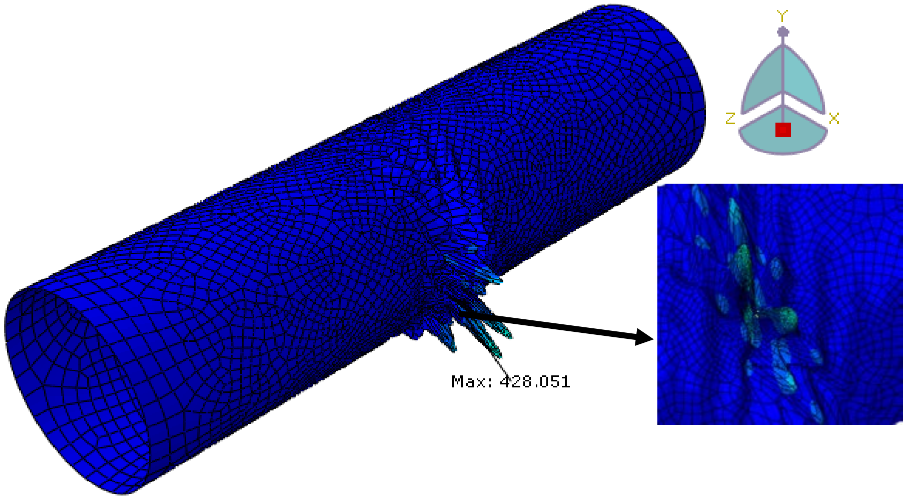


Fig. 12–Buckling effect depending on the orientation of the plies on a pipe provided with a crack emanate notch

5.2 Effect of transversal crack on the buckling parameter

In this section, we investigate the effect of the inclination of the crack and the orientation of the folds on the variation of the parameter buckling. In this case, a cross crack from notch was planned, $\alpha = 90°$ (see Figure 13).

The crack propagations occurred perpendicularly to the x-axis, in other words, parallel to the displacement imposed. The figure 14 illustrates the results obtained. The effect of crack length clearly appears interval between 10° and 40°, it is more important for the larger sizes of cracks. And between the 40° to 90°, the size has no effect significant.

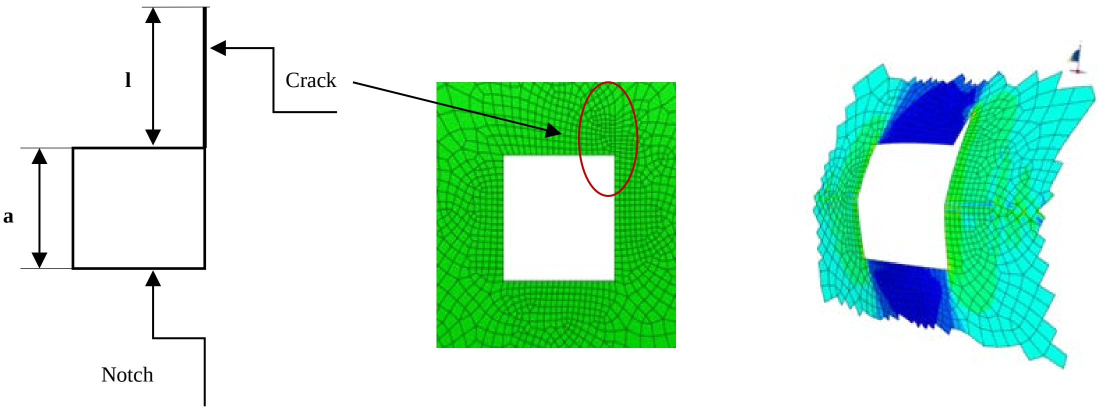


Fig. 13–The pattern and mesh at the notch and the crack inclined at α = 90°

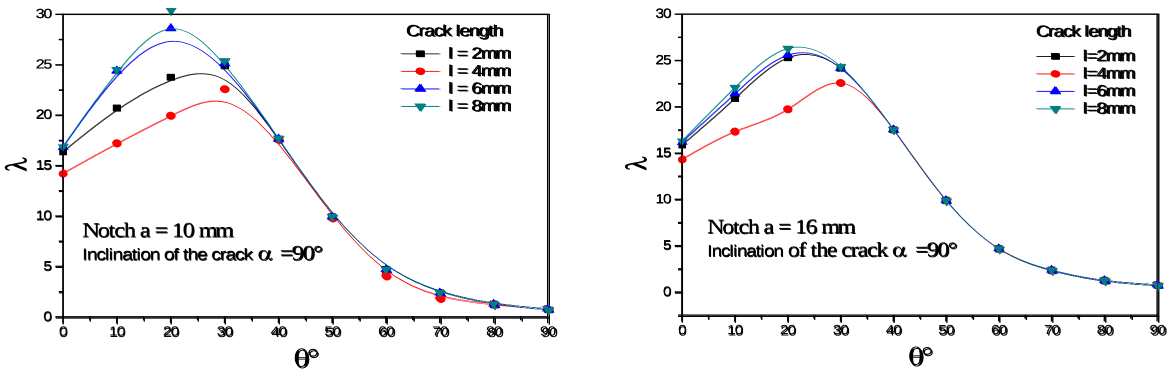


Fig. 14–Buckling parameter variation depending on the orientation of the plies (transverse crack)

5.3 Effect of crack inclined α = 45° on buckling parameter

To better understand the influence of the inclination of the crack emanating from square notch, and to do a little comparison with previous studies, the crack was inclined at an angle α = 45° (Figure 15).

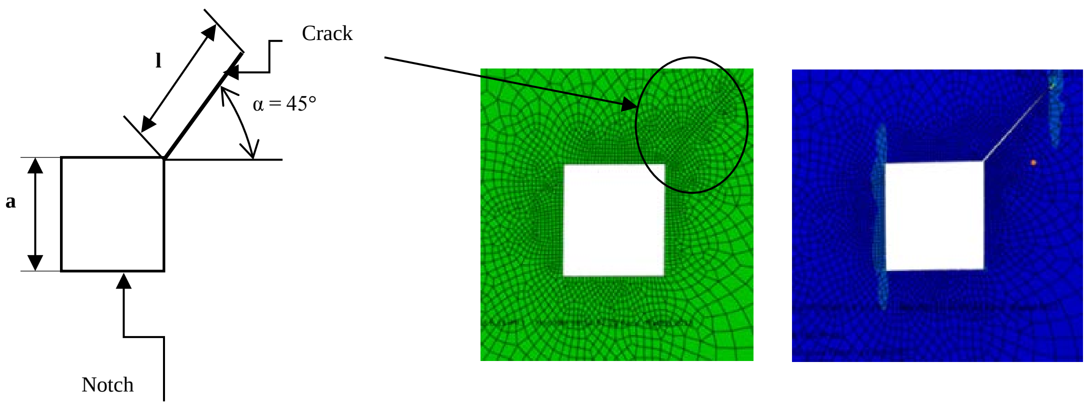


Fig. 15–the pattern and mesh at the cut and the crack inclined at α = 45°

Figure 16 shows the variation in buckling factor function of the angle of orientation of multiple ply crack lengths. The lowest values are obtained for the orientations θ = 90° and larger are θ = 20°. The values are almost the same, indicating that the length of the crack has no effect on the buckling factor. The maximum values are for 20° fiber orientation

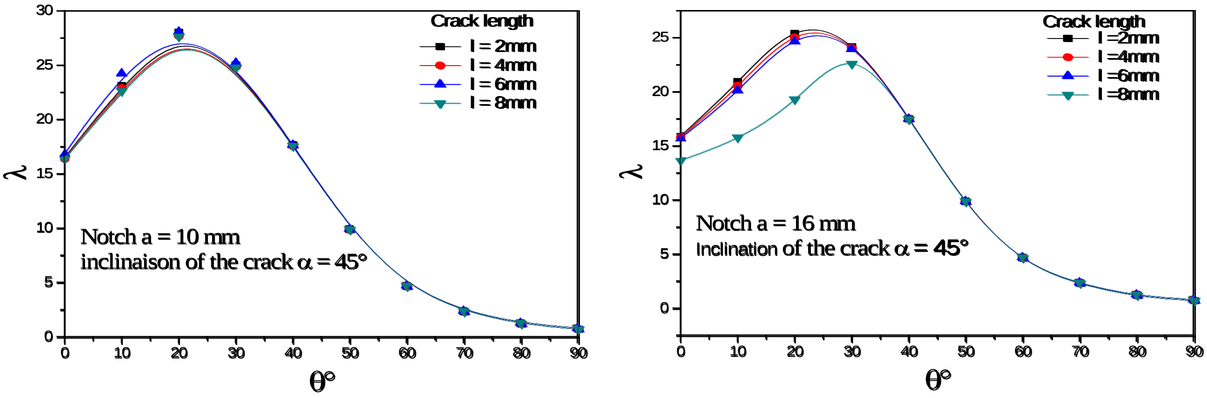


Fig. 16–Buckling parameter variation depending on the orientation of the plies (Crack inclined at 45°)

6 Conclusion

The present study was conducted to determine the effect of geometrical imperfections on a composite pipe subjected to buckling. All results are summarized in the following:

For the compressed pipe, the buckling coefficient reaches the maximum values, and significant, when the fibers are generally oriented at 20°. While the lowest values are obtained when the fibers are oriented in the range of 70° to 90°. The parameter λ decreases with increasing diameter of the pipe. The internal pressure significantly changes the behavior of pipes and λ takes negative and very small values.

Concerning the pipe with notches and without any pressure, the lowest buckling coefficient is obtained in the pipe with larger sizes of notches, regardless the position, size and even the number of those notches. If the pipe is subjected to internal and external pressure, neither the size nor the number of notches has a significant effect on the buckling.

In the case of compressed Pipe with crack emanating notch, the size of the notch plays an important role in the stability of the structure. When the orientation is 20°, this pipe is strongly affected. The length of the crack has no effect on the buckling factor for the inclinations of the crack (α = 0° and α = 45°).

When the crack is oriented to α = 45°, its size has an important effect on the destabilization of the structure in the interval [0°, 45°] of the orientation of the fibers. Beyond this stack and from θ = 45°, it has no significant effect.

References

[1]- D.M. Bigg, Thermally Conductive Polymer Compositions, Polymer Composites, vol. 7, 125-136 (1986) doi:10.1002/pc.750070302

[2]- J. Renard, Elaboration, microstructure et comportement des matériaux composites à matrice polymère, Lavoisier, 2005.

[3]- J.M. Berthelot, Matériaux composites : comportement mécanique et analyse des structures, 4 ième édition, Lavoisier, 2005.

[4]- S. Sessa, R. Serpieri, L. Rosati, A continuum theory of through–the–thickness jacketed shells for the elasto-plastic analysis of confined composite structures: Theory and numerical assessment. Compos. Part-B Eng. 113(2017) 225-242. doi:10.1016/j.compositesb.2017.01.011

[5]- C. Hühne, R. Rolfes, E. Breitbach, J. Teßmer, Robust design of composite cylindrical shells under axial compression – simulation and validation. Thin-WalledStruct 46(2008) 947–62. doi:10.1016/j.tws.2008.01.043

[6]- W.M. Hilburger, H.J.J. Starnes, Effects of imperfections of the buckling response of composite shells. Thin-WalledStruct 42(2004) 369–397. doi:10.1016/j.tws.2003.09.001

[7]- R. Burgueño, N. Hu, A. Heeringa, N. Lajnef, Tailoring the elastic postbuckling response of thin-walled cylindrical composite shells under axial compression. Thin-Walled Struct. 84(2014) 14–25. doi:10.1016/j.tws.2014.05.009

[8]- R. Sliz, M. Yang Chang, Reliable and accurate prediction of the experimental buckling of thin-walled cylindrical shell under an axial load. Thin-Walled Struct. 49(2011) 409–421. doi:10.1016/j.tws.2010.11.009

[9]- R.S. Priyadarsini, V. Kalyanaraman, S.M. Srinivasan, Numerical and experimental study of buckling of advanced fiber composite cylinders under axial compression. Int. J. Struct. Stab. Dyn. 12(4) (2012) 1250028. doi:10.1142/S0219455412500289

[10]- G.P.S. Castro, R. Zimmermann, A.M. Arbelo, R. Degenhardt, Exploring the constancy of the global buckling load after a critical geometric imperfection level in thin-walled cylindrical hells for less conservative knock-down factors. Thin-Walled Struct. 72(2013) 76–87. doi:10.1016/j.tws.2013.06.016

[11]- G.P.S. Castro, R. Zimmermann, A.M. Arbelo, R. Khakimova, W. Mark, Hilburger, Degenhardt R. Geometric imperfections and lower-bound methods used to calculate knock-down factors for axially compressed composite cylindrical shells. Thin-Walled Struct. 74(2014) 118–132. doi:10.1016/j.tws.2013.08.011

[12]- V. Dubourg, J.M. Bourinet, B. Sudret, Fatigue analysis of hull flaring taking into account the randomness and spatial variability of defects in shape and thickness, and material properties. (in Fench) In: Proceedings of the 19th French Mechanical Congress Marseille, August 24-28, 2009.

[13]- T. Kubiak, Z. Kolakowski, J. Swiniarski, M. Urbaniak, A. Gliszczynski, Local buckling and post-buckling of composite channel-section beams – Numerical and experimental investigations. Compos. Part-B Eng. 91(2016) 176-188. doi:10.1016/j.compositesb.2016.01.053

[14]- A. Da Silva, Buckling of thin cylindrical shells under combined loads: internal pressure, compression, bending and shear. PhD thesis, National Institute of Applied Sciences in Lyon, France, 2011.

[15]- L. Ali, E.B. Jalal, K. Abdellatif, E.B. Larbi, Effect of multiple localized geometric imperfections on stability of thin axisymmetric cylindrical shells under axial compression. Int. J. Solid. Struct. 48(6) (2011) 1034- 1043. doi:10.1016/j.ijsolstr.2010.12.007

[16]- M. Bouhafs, Z. Sereir, A. Chateauneuf, Effect of economic and geometric uncertainties on the design of composite pipelines. (in French) In: Proceedings of the 17th National Days on Composites (JNC17), Poitiers-Futuroscope, France, 2011

[17]- K. Bourai, Study of the thermal behavior of a wood-polymer composite for a roto-molding application. (in French) Msc Thesis, Laval University Quebec, Canada, 2010.

[18]- L. Belgacem, D. Ouinas, J.A. Viña Olay, A.A. Amado, Experimental investigation of notch effect and ply number on mechanical behavior of interply hybrid laminates (glass/carbon/epoxy). Compos. Part-B. Eng. 145 (2018) 189–196. Doi.org/10.1016/j.compositesb.2018.03.026.

[19]- J.H.S. Almeida Jr, M.L.P. Tonatto, M.L. Ribeiro, V. Tita, S.C. Amico, Buckling and post-buckling of filament wound composite tubes under axial compression: Linear, nonlinear, damage and experimental analyses. Compos. Part-B. Eng. 149(2018) 227-239. doi:10.1016/j.compositesb.2018.05.004