MODELLING COUPONS AT DOME AREA OF COMPOSITE PRESSURE VESSELS: FROM A 2D-SHELL TO A 3D-SOLID FORMULATION, WITH COMPARISON TO TEST RESULTS

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Abstract

This paper describes a methodology developed to accurately model the material properties in the dome area of composite overwrapped pressure vessels (COPV). First, a COPV is produced on a hexagonal-shaped so-called "soccer ball" mandrel, which has cleverly-designed flat faces in the dome and in the cylindrical regions. Coupons with specific dimensions and stacking sequences are extracted from the cylindrical region of the COPV and are tested, in order to identify the parameters of an advanced intra-laminar damage model for orthotropic plies. Coupons in the dome area are then extracted in longitudinal and circumferential directions. These coupons are flat on one side (the one in contact with the mandrel), and non-flat on the other side. They present a (complex) variable thickness pattern. Starting from a shell model of the coupons developed in a previous paper, a 3D solid-elements model is here developed, in which each layer is represented with its geometrical thickness. We then come up with a 3D model with variable thickness that represents the interlacements of the tapes resulting from the filament winding process. Four-point bending physical tests are conducted on the coupons, and the corresponding FEM simulations are performed. A good agreement is obtained between simulations and tests in terms of stiffness and strength.

1. Introduction

We are in the context of the analysis of carbon fiber reinforced plastics (CFRP) high-pressure vessel (COPV - Composite Overwrapped Pressure Vessel) of type 4, manufactured by filament winding (FW).

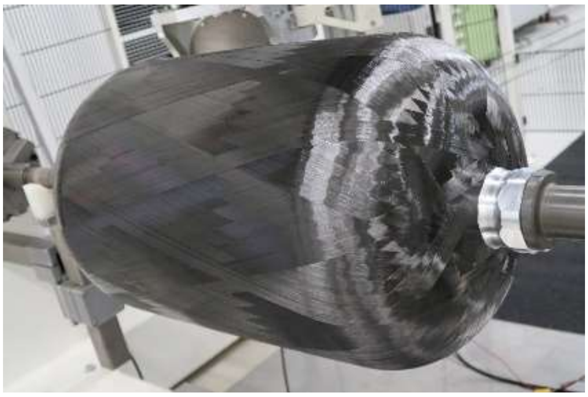

Figure 1. COPV produced by filament winding.

As it is the case for aerospace and automotive applications, efficient design and sizing of COPV must rely on advanced FEM modeling and simulation, on top of physical testing. There is therefore a need for accurate failure analysis in the context of COPV. Classically, the parameters of material models are identified based on flat UD-laminate coupons with specific predetermined fiber orientations (e.g. 0°, 90°, +45°), and based on standards like the ones of ASTM relevant for flat coupons made of UD plies. CFRP manufactured by FW has a unique and complex laminate structure, which presents curvatures, ply interlacements and variable thickness, that make testing and modeling difficult tasks. However, in practice, it is important to use coupons produced with the final manufacturing process for the parameter identification of the material models; if classical coupons produced by e.g. ply lamination are used, the effect of FW structure cannot be accounted for, and cannot be introduced in the material models. In [1], an efficient approach to create representative flat coupons based on the FW process is developed and explained. Flat coupons are created in the cylindrical part of the COPV, as well as in the dome area.

Figure 2. Specific mandrel with flat faces: detail of the filament winding process and tape interlacement at the dome area

In the philosophy of the pyramid of tests, coupons extracted from the cylindrical part are used to characterize the composite material and to determine the parameters of the material model, while coupons coming from the dome area are useful to validate the model and to better understand the damage mechanisms and strength of the material in the dome area, where variable thickness and complex interlacements of the tapes resulting from the filament winding process are present.

2. Material characterization and calibration of the intra-laminar material model

The flat coupons extracted fom the cylindrical part are used to determine the parameters of an advanced material model including non linear behavior and damage propagation [2]. That material model, which is an extension of the Ladeveze CDM model for UD plies [3], is implemented in LS-Dyna via user routines. Standard (ASTM-like) testing (tension, compression, …) is conducted, with cyclic loading when necessary. Next Figure illustrates some results of the parameter identification process (calibration of the material model).

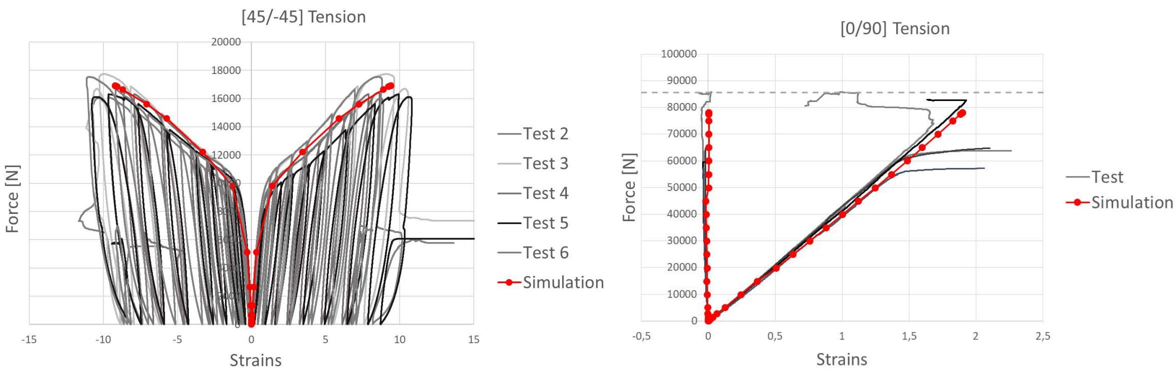

Figure 3. Comparison between test and simulation for the material model parameters identification

3. Modeling methodology of coupons at dome area

3.1. 2D-shell models

In [4], a specific numerical procedure is set up in order to model coupons in the dome area of a COPV. Coupons in the longitudinal and circumferential directions are considered. For modeling, first the tape pattern from the filament winding process is reproduced, and groups of finite elements are defined. The local fiber orientations are then assigned to each group of elements. 2D-multi-layer shell elements are used.

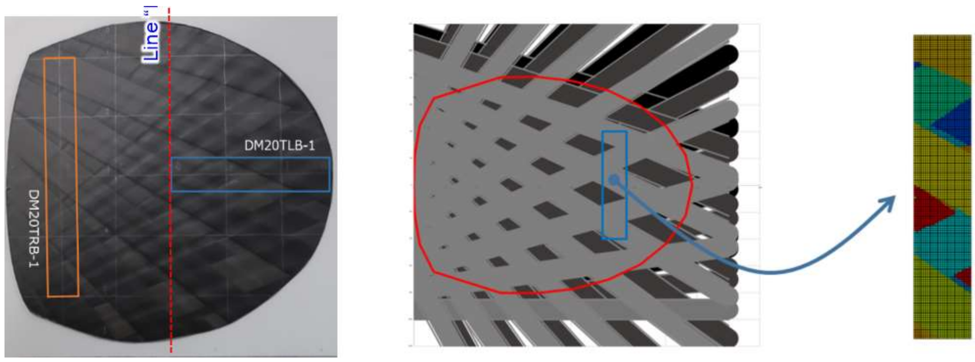

Figure 4. Flat part at the dome area, with indication of locations of longitudinal and circumferential coupons ; complex interlacement of tapes at the dome area of a COPV, and creation of a 2D-shell elements model of a circumferential coupon

3.2. Extension to 3D-solid elements models

Shell models of the previous section are now inflated, in order to create full 3D models built with solid elements. The geometric thickness can now be observed in the finite element model. A typical mesh is illustrated in the Figure below. The material model with parameters identified in Section 2 is assigned to each element, with local fiber orientations coherent with what was defined in the 2D-shell model.

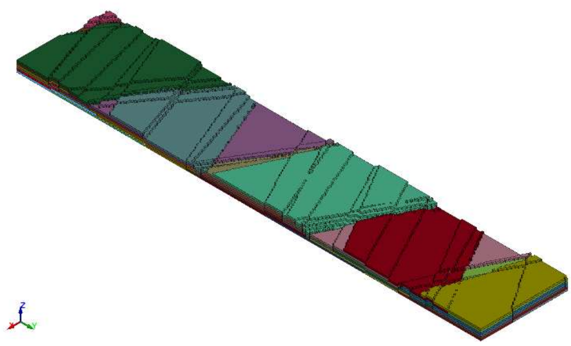

Figure 5. 3D – solid elements FEM model of a coupon at the dome area of a COPV

3.3. Extension to 3D-solid elements models: comparison between tests and simulation

Four-points bending tests are conducted on coupons extracted in the longitudinal and circumferential directions (see Figures 4 and 6). It can be seen in the Figures below that depending on the orientation mechanical responses are very different, bending for circumferential coupons leading to very large dispalcements. We note a good agreement between tests and simulation, as shown in Figure 7 where force-displacement curves are compared.

Figure 6. Physical testing on coupons extracted from the dome area (left: longitudinal direction; right: circumferential direction)

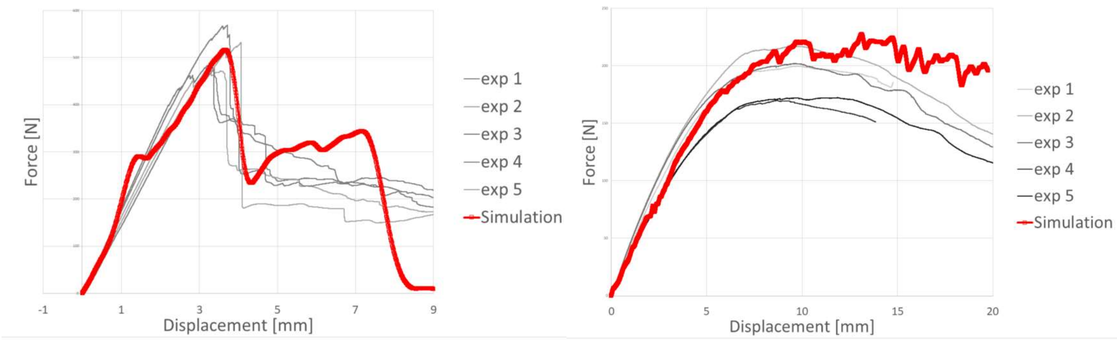

Figure 7. Comparison between test and simulation for 3D – solid elements FEM model of a coupon at the dome area of a COPV (left: longitudinal direction; right: circumferential direction)

4. Conclusions

In this paper, we derived an efficient modeling methodology for coupons extracted from the dome area of a composite pressure vessel. The models are based on 3D-solid elements meshes. Experimental and numerical results are compared for four-points bending ; a good agreement is observed in terms of stiffness and strength.

Acknowledgments

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