

TOWARDS STANDARDIZATION IN COMPOSITE PRESSURE VESSEL TESTING: A BUILDING-BLOCK APPROACH FOR ACCURATE MATERIAL CHARACTERIZATION

Gabriel Eduardo Rojas Valenzuela¹, Miranda Cruz Policroniades¹, Shuyu Song¹, Xianshuo Lyu¹,
Dennis Bublitz¹, Leo Körber¹ and Klaus Drechsler¹

¹Chair of Carbon Composites, Technical University of Munich
Boltzmannstr. 15, 85748 Garching, Germany
Email: gabriel.rojas@tum.de, web page: <https://www.asg.ed.tum.de/en/lcc/home/>

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ABSTRACT

In the application of Composite Overwrapped Pressure Vessels (COPVs), filament winding is one of the most widely used and cost-effective manufacturing techniques. Despite its extensive use over several decades, standardized methods for characterizing wound components, particularly for pressure vessel applications, remain limited. Current standard procedures for determining mechanical properties involve manufacturing samples from flat plate, which are then used for the material card. However, these flat specimens fail to represent key parameters of the actual manufacturing process for pressure vessels, such as compaction caused by the fiber tension [1]. Characterizing flat samples is easier, as the loads and force introduction are well-defined, but these tests fail to represent real manufacturing properties. Curved sample tests, such as the split disk, provide insights into material properties by incorporating real manufacturing parameters but often fail to capture actual failure mechanisms accurately, and defining load introduction is more complex. This highlights the need for an intermediate test for curved samples that balances representative process influence with straightforward load introduction and execution. To better understand material behavior, we propose adapting the building block approach from the testing pyramid [2] for pressure vessel applications, combining tests for flat and curved samples at different pyramid levels, with both physical and virtual testing.

This research focuses on developing a simplified and effective methodology for characterizing wound samples to optimize the manufacturing process. At the element level, the 3-point bending test of curved beams is proposed as an intermediate step between the split disk and flat specimen tests.

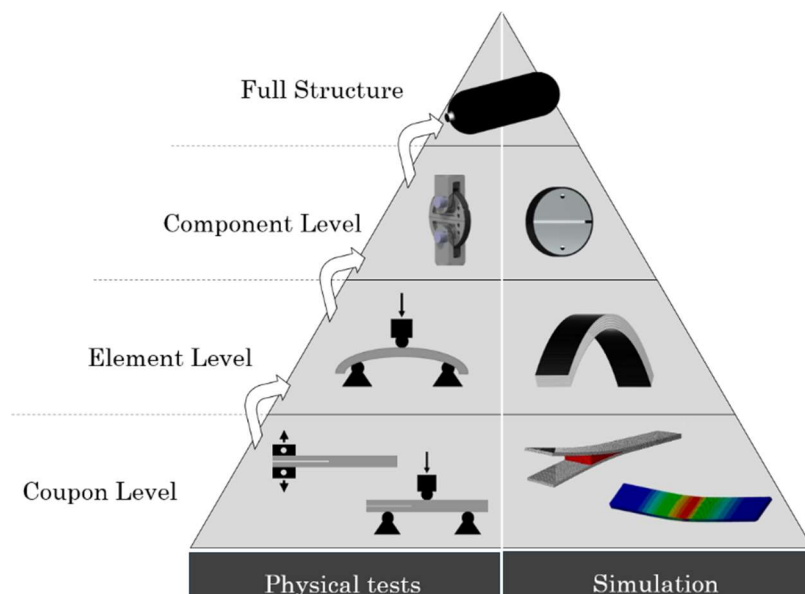


Figure 1: Building block approach for pressure vessel application.

The study adopts a building-block approach to cover the first three levels of the testing pyramid using a commercially available T700-epoxy as material for the investigations. At the coupon level, tensile and compressive elastic properties are obtained using flat samples, along with interlaminar properties. These properties are used to construct a finite element analysis (FEA) model in ABAQUS, employing continuum shell elements and cohesive surfaces to simulate interlaminar failure. The validated FEA model is then extended to the element and subcomponent levels. At the element level, curved beam simulations are performed on a 230 mm hoop-oriented cylinder. A nonlinear geometrical analysis based on Timoshenko's curved beam theory [3] is implemented to determine the hoop stress in the samples, with an elastic 2D solution adopted for validation. Initial tests show good match between the simulation approach and test results (Figure 2b) in the linear elastic range of the specimen.

To highlight the relevance of the curved beam test, wound samples with and without defects are fabricated using the same material as for the flat specimens. Tow overlaps are introduced as a representative defect to evaluate interlaminar quality. Figure 2 shows how the specimen with overlapping tows has a delamination failure, while the pristine specimen fails mainly due to compression, which is also reflected when observing the stress vs. strain plot, providing a foundation for improved characterization techniques and potential standardization.

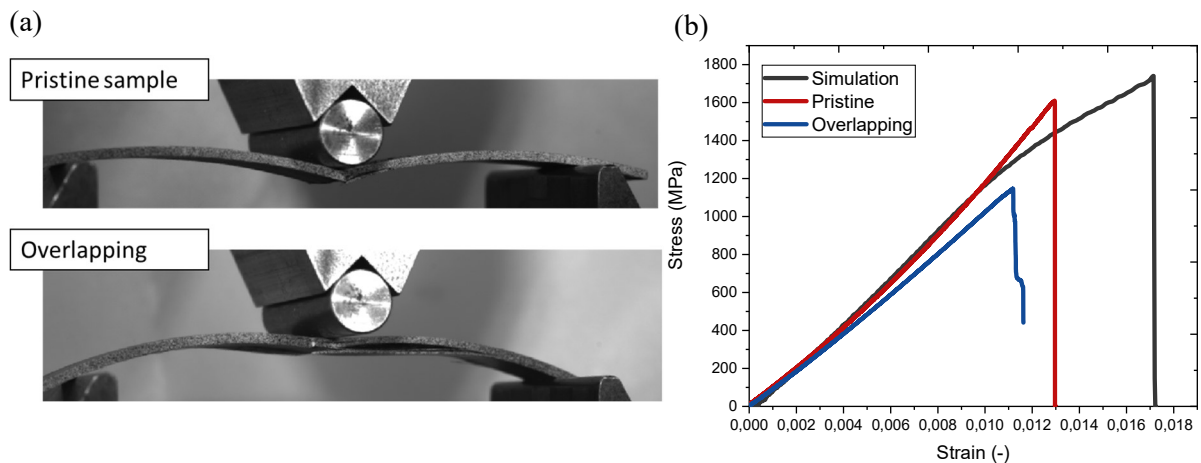


Figure 2: (a) Physical experiment pristine sample and sample with overlapping. (b) Stress-strain curve real test and simulation

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