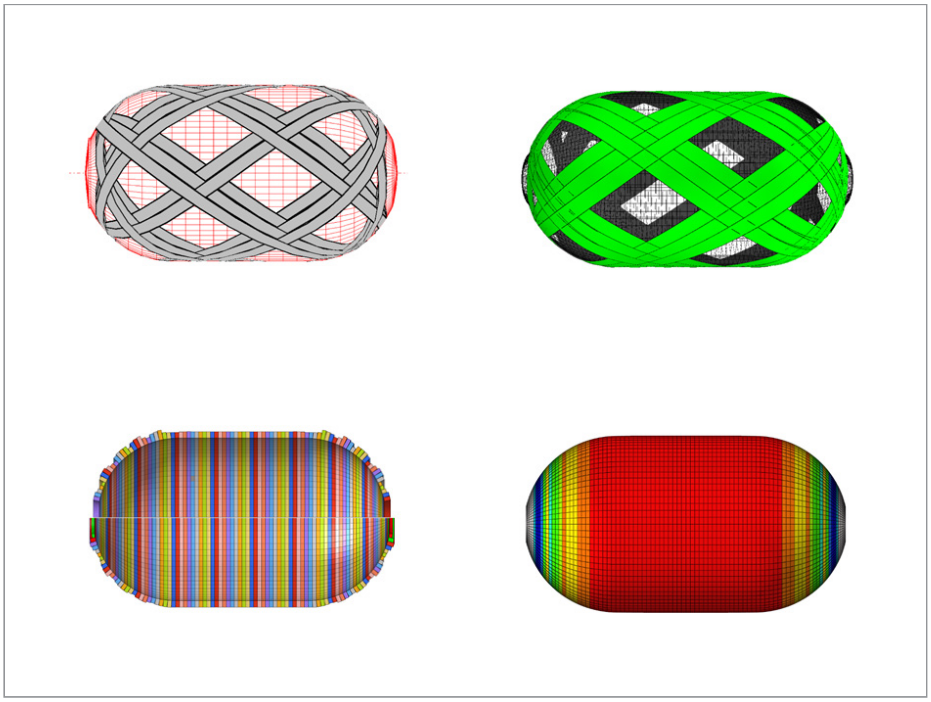
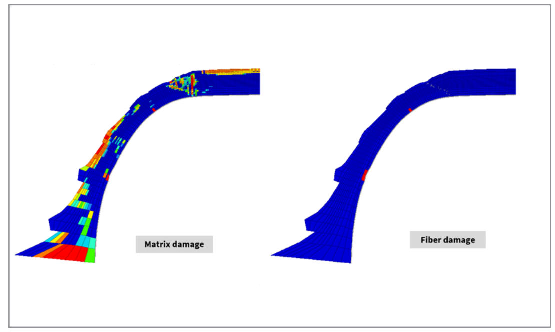
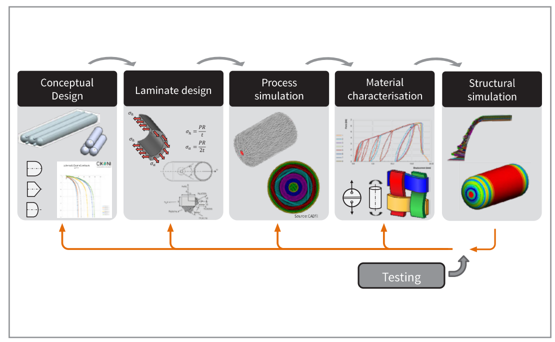
Towards Efficient Composite Pressure Vessel Design

Integrated multiscale approach in the digital workflow for virtual prototyping of Type IV composite pressure vessels (CPV)







Future Mobility Concepts using Hydrogen Fuel Cells

Competing future vehicle concepts have drives using clean energy stored in batteries or hydrogen. On-board storage of high-pressure hydrogen gas to supply fuel cells needs weight-efficient pressure vessels utilizing composite materials, that operate safely and reliably under challenging thermo-mechanical service conditions, be affordable and meet standards.

To date, simulation provides understanding of each factor: geometry, material choice, composite layup, feasibility of filament winding processing. Whereas, a complete workflow shows quickly how the factors interact, leading to optimization of the best candidate construction. Without a digital design-development process, data from each step is obtained by comprehensive physical testing programs: from numerous material coupon tests through to fill-empty cyclic loading, proof and burst tests on many physical protype vessels.

About CIKONI

Based in Stuttgart, Germany, CIKONI is an innovation-focused engineering company that utilizes a unique methodology to develop groundbreaking technologies with composite materials and additive manufacturing. Their goal is to identify new technologies and potential affordances for businesses to advance the design for their current products, software solutions, and manufacturing machines. CIKONI enables clients to deploy these emerging technologies and create next-generation products while being supported from concept to finished products.

Challenges for Designing Composite Pressure Vessels

Composite materials offer a lightweight, durable and corrosion-free solution for gas-containment systems, along with flexibility to manufacture pressure vessels to fit within on-vehicle design spaces, unsuitable for conventionally-shaped pressure vessels, without

Industry

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Challenge

Create an integrated digital design workflow for Type VI composite pressure vessels

Altair Solution

Altair Multiscale Designer, Altair OptiStruct and Altair ESAComp interfaced with third party filament winding simulation package

Benefits

- Virtual prototyping and testing for “what-if” investigations
- Reduced prototypes and physical testing
- Confidence that manufactured vessels will meet certification tests

compromising pressure vessel performance. To boost the ongoing virtual design-development process, CIKONI's goal was to create a comprehensive digital design process and workflow for CPVs, particularly the state-of-the-art Type IV polymer-lined, carbon fiber overwrapped vessels used in vehicles, and reduce the need for extensive, expensive physical testing.

When engineering with composites, the innumerable combinations of reinforcement types and matrix phase, different fiber orientations, along with manufacturing process parameters all contribute to the final structural performance. The challenges identified with the design of composite pressure vessels are three-fold:

- Complex material behavior: For accurate simulation, filament winding paths, material anisotropy and nonlinear damage progression need full consideration.
- Many constituents: Expensive testing for each material and process modification.
- Fast results: Simple modeling and efficient computation to reduce simulation cost.

Partnering with the Altair Composites Team, CIKONI identified the benefits of Altair Multiscale Designer™ to increase simulation efficiency by its virtual material characterization to create accurate and reliable material models for structural simulation.

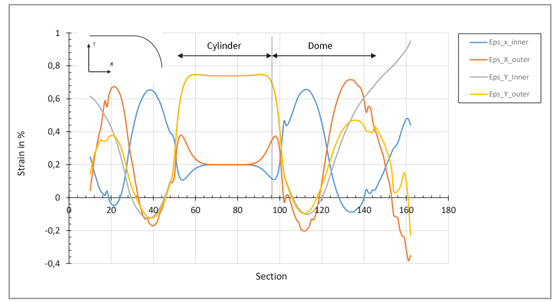
Delivering Faster, Better Understanding of CPV Performance

The CPV workflow starts with defining possible geometries to fit the on-vehicle design space, bearing in mind the vessel's dome regions have a big influence on the mechanical (stress/strain) performance. In the laminate design stage, analytical equations give an indication of thicknesses. A commercial third-party filament winding simulation package provides the basis for the finite element model. Here, Altair partnered with Crescent Consultants Ltd. (UK) for their expertise to help integrate their Cadfil® winding process simulation with Altair OptiStruct™ and Altair ESAComp™.

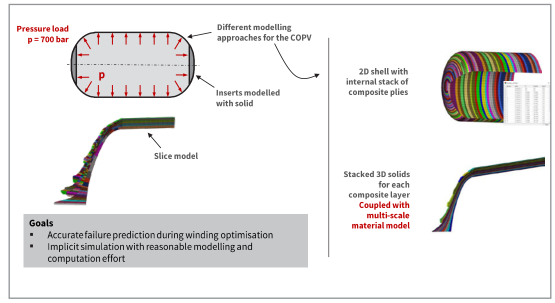
To determine material characteristics, Altair Multiscale Designer – a material modeling open framework – is used effectively to replace the usual Material Card and significantly reduce the coupon testing. A three-step process is used in Multiscale Designer: Define the Unit Cell; Characterize linear material; Characterize nonlinear material. With the Multiscale Designer Material Model established and verified, it is no longer necessary to test every candidate fiber and matrix at different fiber volume fractions.

The vessel modeling approach aims to accurately predict failure during the winding optimization, using implicit simulation, with reasonable modeling and computation effort. A 2D shell model enabled a fast, sufficiently accurate solution to compare concepts, whereas the 3D solid elements, stacked for each composite layer and coupled with Multiscale Designer material model gives high accuracy structural analyses of stresses and strains in the vessel under the operating pressure and burst pressure load cases. Virtual testing is used to verify the structural model, efficiently re-evaluate different steps in the process, to attain an optimized design, e.g. dome design, laminate lay-up, new material models.

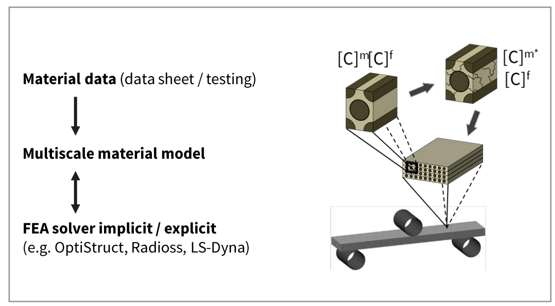
CIKONI's digital design-development workflow integrated Multiscale Designer to increase simulation efficiency by delivering accurate material models quickly. A better estimation is attained of burst pressures and insight into damage mechanisms for different laminate layups at micro-mechanical levels. When combined with filament winding manufacturing simulation, the virtual design process can ensure validation of simulation models for structural optimization of actual layups, along with life predictions.



Engineering the Cylinder-to-Dome Transition Zone of CPV



2D model - fast "what-if" exploration and 3D model for accurate analyses



The Multiscale Designer Process Chain

Cadfil®, a registered trademark of Crescent Consultants Ltd. (UK), is a software solution to program numerically-controlled (NC) filament winding machines to produce CPVs and other closed- or open-ended structural shapes.

Material and images courtesy of CIKONI GmbH, www.cikoni.com.

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