

Simulating Composites: 6 Tips for New Users

Learn from the pros how to design, verify and manufacture composite parts and assemblies.

BY PAMELA J. WATERMAN.

If you've ever doubted that people generally like helping other people, just ask engineers for advice. *DE* did just that, on the topic of what tips to give other engineers working for the first time on a composites-based design project. The floodgates opened: 15 companies shared thousands of words of wisdom on what is clearly a complex but intriguing subject.

Popular for decades in aerospace applications, composites are finding increasing use anywhere that light weight with strength is preferred as an improvement over metal. However, successful composite use involves far more than drop-in replacement. Geometry, material and manufacturing steps must be considered against weight, performance and cost. This complexity has driven dozens of companies to offer software simulation products addressing composite-specific parameters.

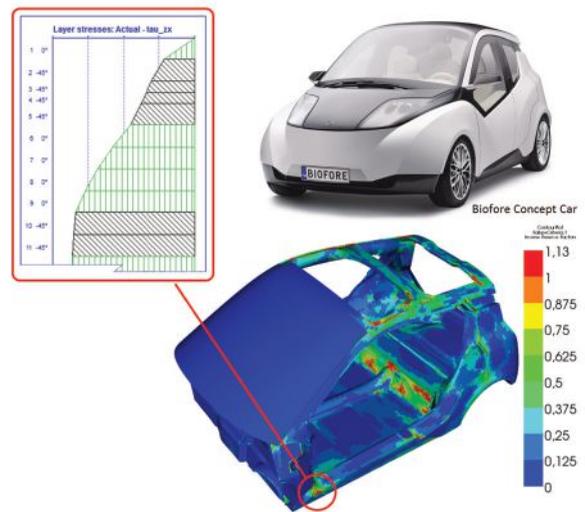
Here's a distillation of the experts' suggestions — what to consider, what to remember, and what not to do when simulating the nuances of composite material behavior.

1. Design with an understanding of the manufacturing methods that could be employed.

Much more than with metals or plastics, composite material behavior depends strongly on the details of both part design and the manufacturing process. Across the board, our experts say that simulations are most useful if tightly coupled and iterated between both stages.

"The best application of composites comes at the beginning of the product design phase, and doesn't simply replace a metal part one-for-one. There are endless combinations of fiber types, matrices, manufacturing methods, laminates and processing conditions (to name a few), and each combination can yield unique behavior. The fabrication method is just as important in the design phase as the design itself," says Angela Schrader, simulation product manager at Autodesk.

This is a sentiment that's echoed throughout the industry. "The number of variables is huge. It's not just the right amount of material in the right place, it's the right material, the right layup and the right configuration that's important," says Rich-

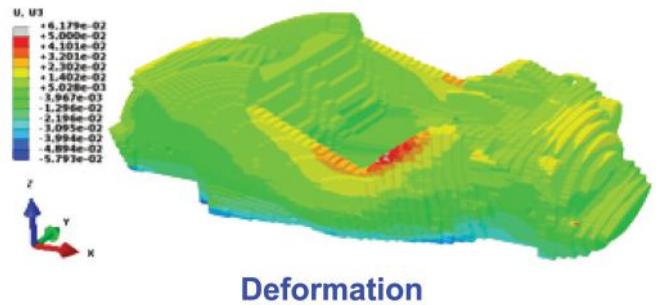


ard Mitchell, lead product marketing manager for Structures, ANSYS. He notes two common decisions designers might face: "Should my part have a foam core, and if so, should the number of layers on each side be equal? And, if I have to add connections to other parts, can I build them into my composite, or do I need to build in mountings for bolts?"

During design validation involving composite materials. One should pay attention to the shear stresses in the out-of-lane directions where allowed stress levels are low. Analysis performed with Compoengineering's ESAComp analysis software. Image courtesy of Compoengineering.

A positive effect of the tight coupling between product and process is increased manufacturing flexibility. This enables use of design elements such as inserts and undercuts that normally would not be allowed. "Thanks to that flexibility, a single composite part can replace several metallic parts assembled altogether. In that case, cost savings can be significant. The counterpart of that flexibility is the number of manufacturing possibilities," say engineers at ESI Group. They add that this counterpart can be

Layer-by-Layer Material Orientation



Mesh generation of a 3D-printed vehicle using Alphastar simulation tools: GENOA De-Homogenized multi-scale progressive failure analysis (MS-PFA) software and Material Characterization and Qualifications (MCQ) Composites Suite, in conjunction with ABAQUS non-linear simulation software from SIMULIA. *Image courtesy of Alphastar.*

managed with simulation tools that promote creativity and support multiple iterations at minimum cost.

2. Learn the nuances of the materials.

Working with composites is so different from working with metals. You may be simulating a part that will be formed by laying up sheets of fiber-embedded materials or your part might begin as a liquid resin filled with short fibers. Consider how heat curing (typically 300-600°F/150-315°C) will affect the final properties. Be sure to get high quality experimental property data.

“How well do you understand the behavior of your composite material?” is the fundamental question posed by Philippe Hebert, Digimat product manager for the e-Xstream division of MSC Software. “High quality experimental data is a must have,” he says. Some problems with composites don’t even have counterparts in the world of metals. If resin accumulates in tight corners, the edge becomes very brittle, an example of how microstructure affects mechanical response.

Several years ago Siemens PLM Software acquired the FiberSim solution for composites design, simulation and manufacture. David Leigh Hudson, director of product and market strategy for the Fibersim portfolio, lists several more considerations, such as controlling springback. “Using accurate local fiber orientations,” he says, “and not just the theoretical orientations, helps to optimize the use of composite materials by minimizing the weight while satisfying mechanical performances.”

In addition to springback, there are other problem areas to consider. “The part normally cures on the outside first,” says Bob Yancey, vice president for Aerospace and Composites at Altair, “which can lock in the shape of the structure and cause residual stresses as the interior cures. Residual stresses can cause part warpage after curing, and failure predictions will be inaccurate if they assume composite, fiber and matrix material are at a zero stress state at rest.”

Another group that understands composites well is the Composites Innovation Centre (CIC) in Winnipeg, Canada, an organization helping clients design, analyze and test products that benefit from use of composites. For establishing best design practices, “all vertical faces should have a minimum 2° draft,” says Alastair Komus, principal engineer at CIC. “If vertical faces in the design are at 90° angles, it makes it very difficult to remove the composite part from the mold without damaging the part and causing extra wear to the tool.”

3. Design to criteria that is specific to composite material applications.

When working with materials and elements for aircraft and aerospace vehicles, pay attention to “allowables” — standardized, statistically derived design values (strength properties). Supporting allowables is one of many features inside Hypersizer, the flagship package from Collier Research that helps designers quantify critical failure modes, reduce structural weight, and sequence composite laminates for fabrication. “The software needs to account

for the fact that the same ply material behaves differently when formed into a sandwich laminate versus a stiffened panel or a solid,” says Craig Collier, president of Collier Research.

Olivier Guillermin, director of strategy, specialized engineering at Siemens PLM Software says: “Use accurate and tight safety margins, identified by using nonlinear analysis, in order to reproduce in the most reliable way the real behavior of the composite structures.” Experience plus insight from simulations helps allow for geometric nonlinearities and damage modes.

ESRD is a company that has worked with composites for more than 25 years. It is dedicated to quality engineering decision making via verification and validation software. Use of its StressCheck product, combined with the company’s Automatic Laminate Builder software, supports estimating interlaminar stresses and strains, necessary for interlaminar failure predictions. Fiber orientations for each ply precisely follow the curvature of the underlying geometry for easy evaluation with StressCheck Fracture and StressCheck Non-Linear Solver modules.

Designers must understand the difference between the physical composite part and the theories formulated to predict its strength, says Barna Szabó, president of ESRD. “Remember to account for the uncertainties associated with numerical simulation,” he says. “Error estimation is essential for certifying design.”

4. Know what you’re trying to predict in your mechanical simulation and set it up accordingly.

Through its Optistruct structural analysis and simulation software, Altair has decades of experience dealing with composites for automotive, aerospace and other lightweight-critical applications. Altair’s Yancey says designers should first determine what they are trying to predict, since the appropriate modeling techniques depend on the goal of the analysis.

“If you are just after stiffness and structural response,” Yancey says, “you can make simplifying assumptions. If you are looking at failure prediction, there are many options depend-

Resources and Composites-Oriented Software Tools:

Because the label “engineering composite materials” applies to short fiber reinforced plastics (SFRPs), discontinuous fiber composites (DFCs), continuous fiber reinforced composites (CFRPs) and a multitude of sandwiching options, it’s no wonder that things get complicated fast. Discussions involve resins and matrices, plies and lay-ups, draping and shrinkage – terms not generally associated with metal part production. (See “Options for Composites Analysis and Simulation,” deskeng.com/de/?p=3613)

Here are some groups and sites to help you dig deeper and work more effectively.

Autodesk – detailed definitions of variables/material properties relevant to composites:

http://download.autodesk.com/us/algos/userguides/mergedProjects/setting_up_the_analysis/linear/Materials/composite_material_properties.htm

cdmHUB.org – online community offering downloadable software tools for working from the cloud, a cellphone, etc.; working on certification of software for composite analysis. See <https://cdmhub.org/resources/948> for initial results.

CGTech – great glossary and explanation of terms: cgtech.com/products/composite-applications/glossary-of-terms/

Composite Agency – CheFEM app quantifies the effects of chemical exposure on various materials including composites: composite-agency.com/product.htm

ESRD – technical briefs on composites verification and validation: <http://esrd.com/Services/TechnicalSupport/ResourceLibrary.aspx>

JEC Group – subsidiary of CPC, The Center for Promotion of Composites, a non-profit association: jeccomposites.com

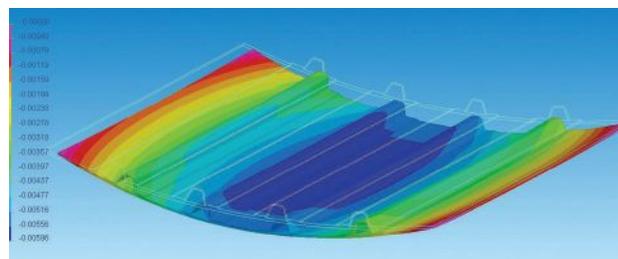
Matweb – material property database: matweb.com/reference/composites.aspx

MSC Software MaterialCenter – a process and data management system linking materials to simulations: mscsoftware.com/product/materialcenter

NAFEMS – courses, conferences, publications, composites working group nafems.org/about/tech/composites/

Society of Manufacturing Engineers – videos, ebooks; joint Composites Conference with Aerodef Manufacturing Conference, Long Beach CA, February 2016: SME.org; aerodefevent.com/composites

– Pamela J. Waterman



A composite aeronautical fuselage panel, showing residual stresses and geometrical deformations, as analyzed with ESI’s PAM-DISTORTION software. The result displayed is the deformation of the part observed after curing. Image courtesy of ESI Group.

ing on the type of failure, loading conditions, and material configuration.” He adds: “Use the right element type. Shell elements are great for in-plane loading but do not accurately capture out-of-plane interlaminar effects. Solid elements more accurately capture (these) effects but can dramatically increase modeling and compute times.”

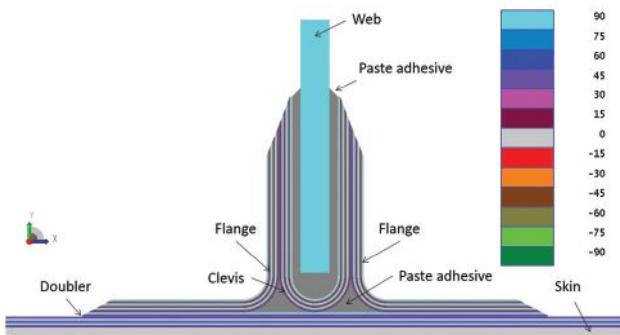
COMSOL is a company known for its multiphysics analysis capabilities. So, it’s no surprise that Bjorn Sjodin, COMSOL vice president of Product Management, says that engineers often cannot neglect heat transfer effects within composites because the part they’re designing may undergo a thermal cycle or be exposed to the environment. At this point it is necessary to model and simulate the interplay between the structural and thermal problem as they influence each other in ways that are difficult to predict unless a multiphysics approach is adopted.

Tightly coupling your design model with the subsequent meshed model will also produce more accurate and faster results. Having bi-directional capabilities (a one-model, virtual twin approach) saves time and ensures the as-built model meets both the design intent and the structural requirements, says Rani Richardson, senior business experience consultant for Dassault Systèmes’ (DS) CATIA division. CATIA software incorporates several composites simulation tools acquired through the 2011 DS purchase of Simulayt.

5. Start small with behavior simulation, verify with test samples then model the larger system.

Experts in other DS divisions offer equally pragmatic points of view on making composites simulation work. “When asked for the time, don’t build a watch. Create simple simulations to understand the major aspects and performance of a product. Every simulation does not need to be a complex delamination study, but when possible include the true fiber angles,” says Greg Albrechtson, user experience engagement manager for DS SIMULIA.

EsaComp from Compoengineering is another tool for composite design and analysis, originally developed for the European Space Agency but expanded to other applications including automotive. There is value in building up your model. “Use simple



Ply-layup configuration of two composite sheets joined at right angles using a “Pi” joint (upside-down Greek letter pi). This structure offers the maximum surface area between the adhesive-coated surfaces. Diagram with labeling shows ideal situation of the joining structure, typical for assembly on an aircraft, for analysis with ESRD’s StressCheck software. Image courtesy of ESI Group.

models created with FE software,” says Hari Katajisto, engineering consulting at Componeering, “or use dedicated composite design software to decide what are the design drivers. Continue with more detailed models using more accurate material data.”

While accurate simulations based on composites generally must include such effects as heat transfer, the first cut of a design can be evaluated in smaller sections to help zero in on behavior. “Engineers typically verify their model by evaluating the thermal stress and displacement in each layer of a few-inches-square sample of the composite structure layup. Handling a smaller model is faster and allows, early in the design process, catching any errors due to modeling choices and parameters and properties used,” says COMSOL’s Sjodin.

6. Simulate the actual manufacturing process.

Unique to composite manufacturing are such terms as angle, alignment, draping and fiber- or tape-laying. Layers are typically stacked with their fibers oriented at 0°, 45° or 90° to the previous layer. ANSYS’ Mitchell describes why precision matters: “If one of my pieces of fabric is not laid correctly and sits a degree or two out of alignment, how does that affect the draping as the material goes around a corner?” And Collier says it’s important not only to minimize laps, gaps, bridging and fiber buckling in the design but also to include a statistical viewpoint of these defects in simulations.

Several more companies offer software that simulates the actual manufacturing process, whether that involves laying material by hand or automatically. Anaglyph’s Laminate Tools serves first as a pre- and post-processor for FEA (finite element analysis) of composites and then as a generator of ply layout information. Anaglyph’s PlyMatch tool offers visual projection technology to accurately guide hand-done ply placements.

To learn more about automated fiber placement and tape-

laying equipment, read the interesting overview and watch the video by CGTech (cgttech.com/products/composite-applications/composite-software-overview/). The company’s specialized VERICUT Composite Paths for Engineering (VCPe) software lets you view a simulation of the path that will be taken by automated fiber placement and automated tape-laying NC equipment. A third supplier in this area is Spring Technologies; its NCSIMUL Machine Composites software simulates lay-up of fiber ribbons or filament winding, with cutting control for each fiber, layer-by-layer viewing, and measurement of ply thickness, angles and distances.

Anoush Poursartip, director of research at Convergent Manufacturing Technologies (developers of COMPRO pre/post-processing software targeted to composites), sums up the challenge well. “Composites simulation, and composites manufacturing simulation,” he notes, “can be an expensive proposition with low ROI if implemented bluntly. Effective composites manufacturing simulation software vendors provide a systems approach, helping designers and manufacturers evaluate their manufacturing facilities, characterize materials, perform the simulation, change workflow and practices to accommodate new methods, and even provide instrumentation and measurement capabilities for in-factory production monitoring.” All good reasons to follow up on the tips in this article. **DE**

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