Lighten up! Amcor Uses Realistic Simulation to Stay on Top in Plastic Container Market

Abaqus FEA helps industry giant slash design cycle time, reduce unit weight and enhance product performance

Image courtesy of Amcor

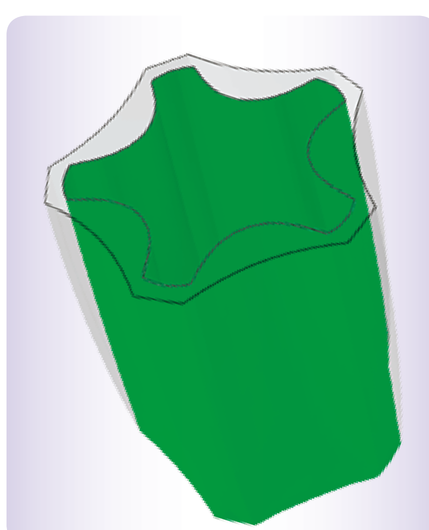
The dynamic, competitive landscape of the consumer packaged goods (CPG) industry demands nimble, adaptative strategies. PET (polyethylene terephthalate) plastic container manufacturers are juggling business consolidation, increasing government regulation, and the need to demonstrate corporate and social responsibility. At the same time, ever-changing consumer preferences as well as energy and raw material costs are driving an exponential expansion of product portfolios. The PET customer is demanding that manufacturers develop a wider variety of top-quality, innovative containers in ever-shorter time periods and at lower unit prices.

To meet these challenges, the world's largest supplier of PET containers, Amcor's Rigid Plastics Division (renamed from Amcor PET after its parent bought Alcan in late 2009), has found a way to significantly reduce costs—from product design to materials parameters to methods of production—while adhering to strict industry performance standards. They use Product Lifecycle Management (PLM) solutions from Dassault Systèmes to integrate 3D virtual design, finite element analysis (FEA), and collaborative product development software into their product design and development process.

The results: a 50 percent drop in design cycle times, enhanced communication between designers and engineers, less physical prototyping, and faster time-to-market. Plus quicker, more creative response to customer requests for new ideas—and lighter-weight, high-performance product solutions that lower everyone's costs all along the supply chain from raw materials to transportation.

A few grams shaved means millions saved

Amcor's Rigid Plastics Division has 63 facilities in 12 countries that provide packaging for many of the world's leading brands of carbonated soft drinks, juices, teas, water, condiments, salad dressings, sports drinks, soaps, shampoos, pharmaceutical and health care products. The Michigan-based division produces about 25 billion units of bottles, jars, cans and other product configurations per year. Multiply that number by even a few grams saved per unit and the sustainability impact is staggering. "A container made with too much, or too little, material can be very expensive," says Amcor's Advanced Engineering Services group manager Suresh Krishnan. "Too little material can lead to containers failing, and too much can cost us a fortune. 'Lightweighting' our products is one of the key things that has sustained Amcor against our competition during these tough times, and computer-aided engineering (CAE), within a PLM environment, has been critical to achieving that."



"Origami" concept vacuum panels are included in a PET container for designed collapse that compensates for shrinkage during cooling to maintain structural strength and integrity. Original shape is clear, final shape is green.

The goal of "lightweighting" resonates with engineers in every industry, from aerospace to cell phones. But the weight savings of plastic over glass have dramatically transformed the liquid container business in recent decades. While glass has been used for centuries, and its physical properties are well known, the move to PET in the 1970s required a step-up in sophistication on the part of manufacturers.

Simple product, complicated design challenge

"A PET container is a simple product, but it's a complex design problem to make it right," says Krishnan. For example, the popular two-liter carbonated soft-drink bottle, seen on supermarket shelves everywhere, has to be custom-designed to individual brand specifications and must retain its blow-molded shape during cold-filling, carbonation, sealing, labeling, packing and shipping (hot-filled containers need to withstand additional temperature, vacuum and pressure fluctuations). No container should fail if accidentally dropped, nor excessively dent or lean when stacked.

To cost-effectively produce such a high-performance product, Amcor's Advanced

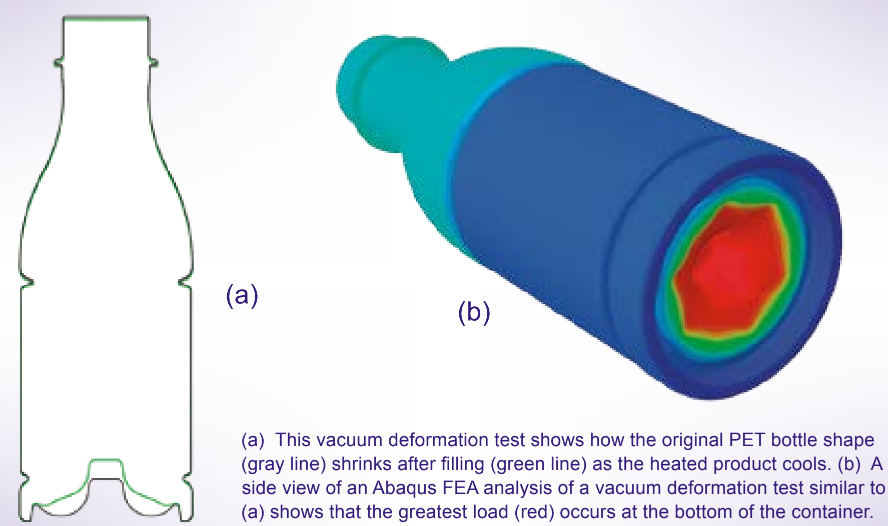
Engineering Services group uses computer modeling to simulate, or virtually test, the behavior of a bottle under these diverse loads and stresses while it's still in the design stage. At the core of their regimen is Abaqus Unified FEA software. Amcor employs Abaqus to generate simulation data that can guide design modifications, material thickness parameters, even manufacturing processes, in order to reach the lightest possible result that satisfies both customer and regulatory requirements.

Visualizing the challenges

Based on an initial concept that the industrial design department has worked out with the customer, the design engineers start by building a 3D virtual model in CATIA. They then use customized scripts and knowledge templates within CATIA to accurately determine the critically important surface area, volume and weight for the bottle's final design. "CATIA's capabilities save us a lot of time," says Krishnan. "Whenever the analysis shows that we need to make a design change, we can do so and the model automatically adjusts to reflect that. And instead of starting a new design from scratch, we can begin with an existing design and quickly modify it."

Next, the engineers mesh the geometry of the virtual bottle with either Hypermesh or Abaqus/CAE ("our designers are increasingly using Abaqus/CAE because it has a CATIA-like look so it's easier for them to work with," says Krishnan), then bring it into Abaqus Unified FEA for physics-based performance simulation. A typical Abaqus model for a top load analysis (such as bottle capping, or container stacking) has about 150,000 shell elements and about 350,000 degrees of freedom. A more complex, Coupled Eulerian-Langrangian drop analysis (which simultaneously shows the fluid-structure interactions between a container, its contents, and the floor) can have up to 800,000 d.o.f. The group runs its analyses on a Microsoft Windows HPC Server.

Amcor tried a different FEA software in the past, but realized they were not getting satisfactory results and switched to Abaqus, a change that empowered the group to begin exploring the full scope of its design challenges. "Abaqus was the better choice for us because it offered a breadth of simulation disciplines that cover more significant performance requirements for PET containers," says Krishnan.



(a) This vacuum deformation test shows how the original PET bottle shape (gray line) shrinks after filling (green line) as the heated product cools. (b) A side view of an Abaqus FEA analysis of a vacuum deformation test similar to (a) shows that the greatest load (red) occurs at the bottom of the container.

Kicking the container around with simulation

It offers quite a range of disciplines. The group began with top loading and vacuum pressure simulations. They moved on to drop-testing, blow molding, conveyance, denting, and leaning. They are currently working on pasteurization and retort (heating during sterilization) simulations. They're even starting in on ergonomics, to simulate the effects of a human hand putting pressure on a container. "Being able to simulate multiple load conditions at the same time is very important to us," says Krishnan. "You have to take into account a number of parameters simultaneously, such as fluid-structure interaction, temperature, pressure, and material strain rate."

With their FEA results in hand, the Advanced Engineering Services group has a clear vocabulary for discussing the viability of a design with the industrial designers. Using multiple iterations between CATIA and Abaqus, the parties can collaborate to arrive at the best solution that validates the appearance, performance and functionality of a particular container. Such improved communication pays off: "One of our performance metric targets was to reduce the number of design revisions we made by 20 percent in a year," says Krishnan. "Right now we are well ahead of that goal."

"The benefits from virtual testing can extend beyond the testing laboratory all the way to manufacturing," Krishnan says. "When we achieve an optimum top load value via simulation, we can use that data to provide actual section weights to the process engineers in the plant, so they can more easily produce the container that gives the desired performance."

PET plastic behavior is complex

The PET material itself brings unique challenges to this whole process. PET is highly nonlinear, with biaxial properties that vary with the amount of stretching it undergoes. A semi-crystalline thermoplastic, PET softens at a "glass transition temperature" of approximately 76 degrees C. Above that, it becomes elastic and can be formed, a property effectively utilized in the stretch blow molding process.

But when PET containers are filled with a hot liquid, they are susceptible to shrinkage back towards their "remembered" previous shape (the preform), a characteristic that has to be taken into account when designing the initial container configuration. The bottles also collapse slightly due to vacuum pressure resulting from cool-down after hot-filling. So the design for a hot-fill PET bottle includes 'vacuum' panels for designed collapse. "We can now easily model these kinds of physics-based characteristics with Abaqus FEA, using a customized script for hydrostatic fluid elements that enables us to accurately simulate the behavior," says Krishnan.

The contents of every type of PET container must also be taken into account in Amcor's simulations, from adjustments in the density and viscosity values of liquids (from pure water to sticky paint) to the internal pressure fluctuations inherent to carbonated soft drinks.

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Amcor continues working on advanced material properties for their models. While PET is 100 percent recyclable, containers made from recycled PET (RPET) may have slightly different material properties than the originals. Initiatives also are underway in the industry to develop biodegradable PET using ethanol. "Although we are not simulating either of these materials at the time, this is certainly a consideration for the future," says Krishnan.

Managing all that data

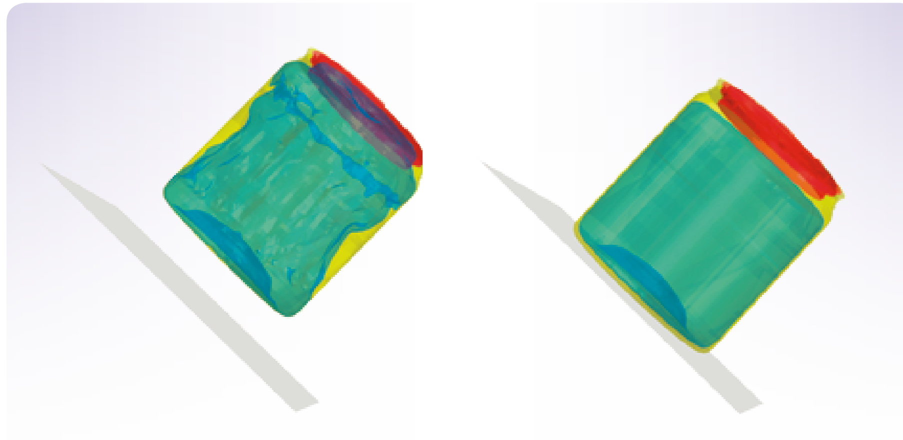
It all adds up to a vast amount of simulation data. Amcor keeps track of everything the Advanced Engineering Services group generates by using Dassault Systèmes' ENOVIA solution for collaborative product development, which facilitates the organization and easy retrieval of all CATIA and Abaqus data for each container design while managing all processes to keep them in synch.

"Whoever in our organization—from the Advanced Engineering Services group of 14 engineers all the way to our manufacturing plants—needs information about a specific project, they can pull up the report in ENOVIA and find the latest version, completely standardized, which is very helpful," says Krishnan. "ENOVIA automatically saves the history of every previous iteration as well, allowing for easy reference, tracking and communication among our project teams."

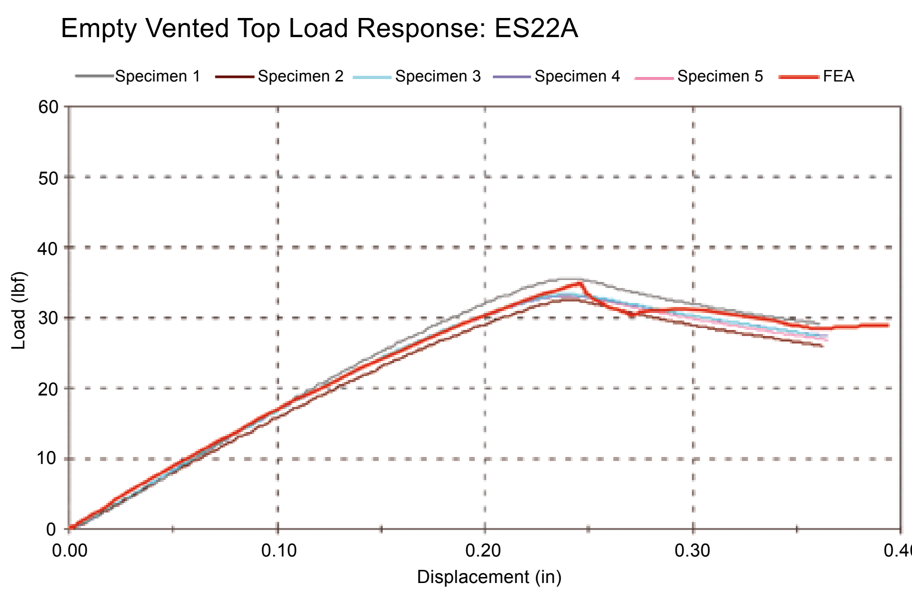
Results rise to the top with simulation-driven lightweighting

The growth of Amcor's physics-based simulation capabilities has been the driving force behind the company's lightweighting initiative. Krishnan cites one example where a 63-gram container design was reduced to 43. "We used realistic simulation to validate performance while trying out various Amcor-developed technologies and eventually met all performance requirements with the lighter design," he states. "Simulation helped us try many more options than we normally would and compare multiple designs with one another."

Although Amcor still validates their virtual tests with physical testing, the ever-increasing accuracy and refinement of their computer predictions has allowed them to decrease physical prototyping dramatically. "We see a close match between the curves that Abaqus provides and the test results so we've got a lot of confidence in simulation now," says Krishnan. "We've cut our design cycle down to nine months from 12 to 18, which has significantly reduced our product development costs. And we've gained a lot of management buy-in to our methodology."



Abaqus FEA container drop test uses a Coupled Eulerian-Lagrangian analysis to show the interaction between the container, the fluid it holds, and the surface it impacts. The top must stay on even when the container is dropped 3 ½ feet to a hard floor.



Graph of empty vented top load response test results shows how accurately Abaqus FEA (red line) predicted the behavior of the container.

CAE promotes creativity

The use of CAE has proved of value for Amcor when proposing new ideas to clients, Krishnan says. "We include animations of our Abaqus simulations in all our presentations. We can demonstrate how we create a design, perform FEA on it, and try out as many options as we want." Any industrial design proposal can be quickly simulated; if a customer puts in a request in the morning, animations can ready by that evening. "It really frees the designers to explore whatever ideas they have," says Krishnan.

"It's a fast-changing business and the next new design is just around the corner," he adds. "Somebody else is always looking to capture that design so we have to be really fast—and with CAE in our arsenal, we are."

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