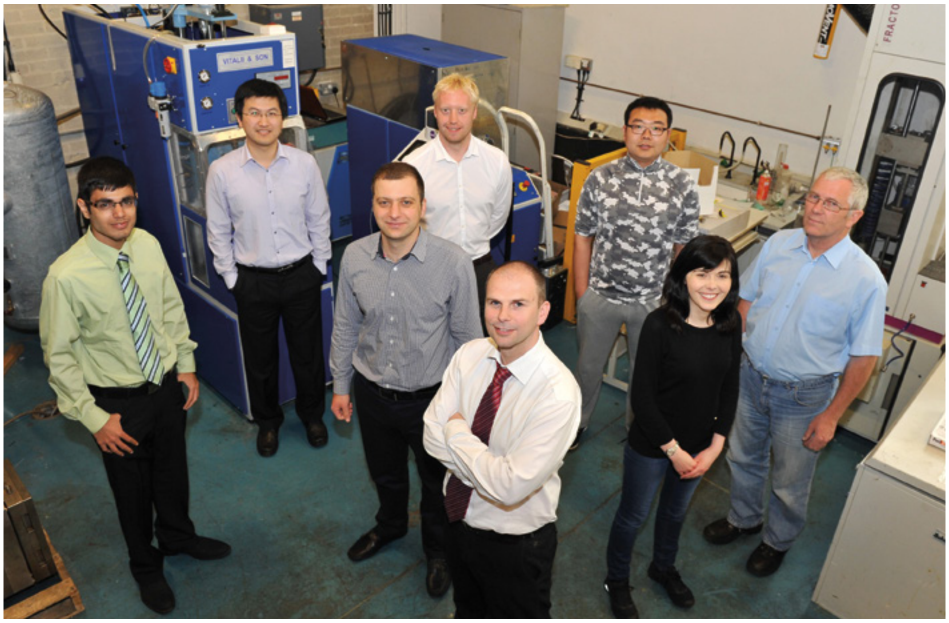
Perfecting the Plastic Bottle, Blow by Blow

Queen's University Belfast researchers use realistic simulation to fine-tune bottle blow-molding methods



Gary Menary (front) and the Advanced Materials and Processing team in their test laboratory at Queen's University Belfast.

What do medical angioplasty balloons, car airbags and plastic bottles have in common? More than you might think. All of them are made from polymer materials that need to expand from a compact shape into something bigger—manually during surgery, through a sudden burst of gas in an auto collision, or via a fine-tuned balance of temperature and air pressure in a bottle blow mold.

High-level know-how about this last methodology can be found at the Advanced Materials and Processing group based in the School of Mechanical and Aerospace Engineering at Queen's University, Belfast, Northern Ireland. With ongoing pressures to use less material, produce stronger containers, and redesign plastic bottles according to customer demand and consumer whim, the economic stakes remain high. The University's skill set is now in demand from leading multinational companies around the globe.

"The challenge our industrial partners face is to make a bottle with as little material as possible, yet still have the proper end-service performance requirements," says Dr. Gary Menary, Senior Lecturer at the School. "It's a very competitive field. A typical large scale converter makes about two billion bottles annually. So one gram taken out of a bottle for them translates into two million kilos of material, equating to $3M saved per year.

"The problem is, the process continues to rely to some extent on trial and error," he says. "Even now we hear of engineers who come up with a new bottle idea and bring it down to the shop floor to manufacture different shapes while guessing the proper design and production conditions. It's still a bit of a black art all around."

Transforming a "black art" into a scientific approach with simulation

Beginning in 1991, Queen's engineering professors received funding from the U.K. Research Council with the objective of removing all the trial and error from the injection stretch blow molding (ISBM) process. "This started as a three-year project, but twenty years later we're still working on it, although with a far more sophisticated toolset," says Menary.

Almost from the start, the research team began collaborating with manufacturers, from a local Irish company, to Coca-Cola headquarters in the U.S., to a plastic bottle development project that involved 16 European partners in a 50/50 split between industry and academia.

"Our industrial collaborators have helped keep us on track," says Menary. "They tell us what needs to happen, why we need to do it, what works well and what doesn't. These relationships have been evolving all along, giving us real-world feedback on what we are trying to accomplish."

Abaqus chosen for model customization and nonlinear capabilities

The primary simulation tool for Queen's all along has been Abaqus FEA software from SIMULIA. Fundamental to the team's work from the beginning was characterizing the material from which a plastic bottle is made. "No matter what the product, the behavior of the polymer material is the most difficult aspect to model when you are trying to simulate how it inflates," says Menary. "Abaqus gave us the ability to code our own material models and customize our analyses. Our Abaqus simulations provided the necessary scientific approach that takes material characteristics into account when creating and evaluating designs."

As they worked to refine their Abaqus models, the team realized that current testing technology didn't give them all of the input data they needed for their simulations, so they developed several of their own laboratory instruments to provide it.

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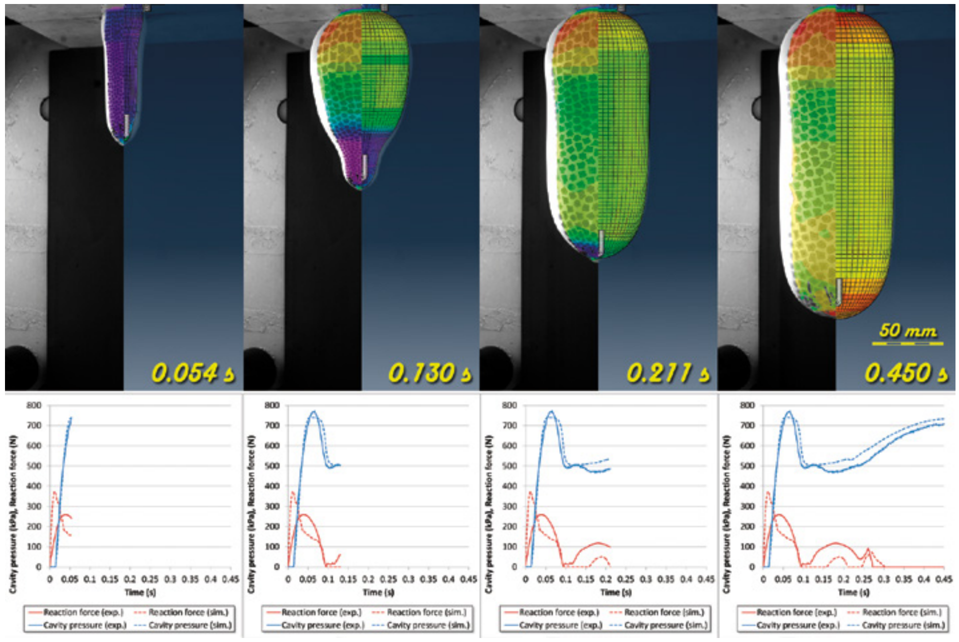
"One of the major difficulties faced by previous researchers in modeling the ISBM process was the inability to fully represent the deformation behavior of the PET polymer," says Menary. "Prior work definitely advanced the knowledge base, but our own tests provided validated data on which we could confidently build our library of Abaqus FEA models." The issues to be explored were diverse, because the performance of a blown bottle depends on many variables: the preform dimension, preform temperature distribution, stretch-rod displacement, pressure blowing profile, and cooling rate applied to the blown bottle.

Blowing up the problem to size

"Blown" is the keyword here. Earlier models that the Queen's group evaluated all made a critical assumption: that uniform pressure was being applied inside the preform as it inflated. "However," says Menary, "as the PET material expands, pressure inside the membrane is not uniform: It varies depending on the rate of air flowing into the system as well as the concurrent expansion of the membrane."

This changing pressure phenomenon is understandably difficult to observe when a bottle is being inflated inside a sealed mold. So in order to fully characterize the inflation process, the group decided to investigate the inflation of the preform unimpeded by a mold, in "free blow."



Free blow experiment on an instrumented, marked PET bottle prototype allowed a perfect synchronization between force, displacement, and pressure measurements of the stretching and blowing stages of the bottle blowing process. Above are results from image capture using a high-sampling rate video camera and the corresponding predictions from the Abaqus FEA simulation. Contours are of axial strain.

A preform of molten PET plastic (with thin stretch rod visible inside), en route to a blow mold where it will be injected with air to expand it into a plastic bottle.

Using a digital image correlation system, the engineers could then inflate a preform with a pattern applied to it, and then track the stream of expanding material against time from the discrete locations marked on the preform.

The data from these free blow experiments were then used to calibrate Abaqus FEA models for a more realistic simulation of bottle inflation response to fluctuating pressure changes. "The mass-flow rate method in Abaqus was most accurate for modeling pressure input in our ISBM simulations," says Menary.

Going inside the mold with simulation

With a clearer understanding of the role of pressure from their validated free-blow models, the engineers have since turned to simulating the process inside the mold itself during ISBM, including the all-important role of the stretch rod inside the preform. "The sequence of the stretch-rod movement and the onset of the pressure are key to controlling the proper distribution of the material in the process," says Menary.

Menary's vision is to link everything together with simulation, from bottle and preform design and process conditions, to thickness distribution and mechanical properties. "The data from the manufacturing process simulation can then be transferred to virtual packaging tests where you can see how the preform design affects things like bottle drop or top-load performance, even shelf life," he says. "You could couple all this with optimization software like Isight [also from SIMULIA] to pinpoint optimum process or minimum material—whatever you need."

In the future, Menary sees new materials challenging his group. "We have a pretty good handle on the behavior of PET right now," he says. "Next we may turn to modeling the new plant-based plastics. Our Abaqus FEA tools will continue to aid us in finding solutions that help the bottling industry move forward."

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