Deformation Behaviour Analysis of PET Bottles in a High Speed Labeller

This article describes an explicit LS-DYNA analysis of the deformation behaviour of filled and capped PET bottles in the high-speed labeller.

The increasing use of PET bottles has been and continues to be a dramatic growth story in the packaging industry. Increasing use means an increase in demand, and the need for saving time in the process chain of the packaging industry. One area where a high-speed process is possible is labelling. State-of-the-art labellers are capable of labelling 60,000 and more containers per hour.

However, in higher labeller output ranges, PET bottles are subjected to undesirable deformations, due to their lower Young's Modulus and much thinner walls as compared to glass bottles.

For a particular machine speed, information on the deformation behaviour during the early stages of machine planning will be useful. To obtain this detail, the explicit FEM software LS-DYNA was used for this project.

Objective and tasks

The sequence of steps carried out is

- top-load simulation and verification of the empty PET bottle: to obtain a reliable empty PET bottle model
- top-load simulation and verification of the filled PET bottle: to obtain a reliable filled PET bottle model
- process simulation of the filled PET bottle in the high-speed labeller: to inspect the deformation behaviour of the PET bottle

Quasi-static buckling analysis of the empty bottle

Prior to the quasi-static buckling analysis, sensitivity studies were carried out with respect to material, geometry and finite element parameters so as to obtain an optimised parameter set. This set, when used in the quasi-static buckling analysis, yielded a nice fit of the pre- and post-buckling behaviours with the test data (Fig. 2), thus validating the reliability of the optimised parameter set. The moderate differences observed in the load-displacement curves is mainly due to the use of a simple material model (*MAT_PIECEWISE_LINEAR_PLASTICITY) in LS-DYNA, which does not cover the complex behaviour of PET material in reality.

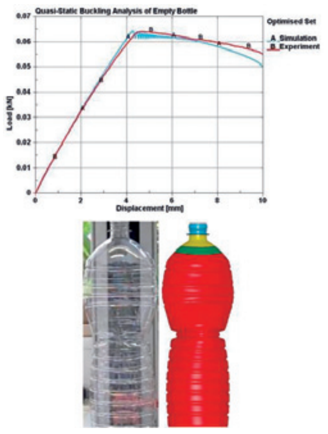

Fig. 2: Structural Response of Empty Bottle

Type 16 (fully integrated) shell elements with proper warpage treatment were preferred to Type 2 (reduced integrated) shell elements so as to avoid non-physical initialization of buckling.

Quasi-static buckling analysis of the filled bottle

Having now obtained a reliable empty bottle, presence of water and air along with its physics (compressibility, inertia and hydrostatic pressure) need to be accounted for a filled bottle. **C**ontrol **V**olume (CV), **S**moothed **P**article **H**ydrodynamics (SPH) and **A**rbitrary **L**agrangian **E**ulerian (ALE) methods were evaluated in LS-DYNA for ease of implementation, computation effort, and most importantly, to accurately simulate the liquid physics involved. Studies performed on these three approaches have shown the following:

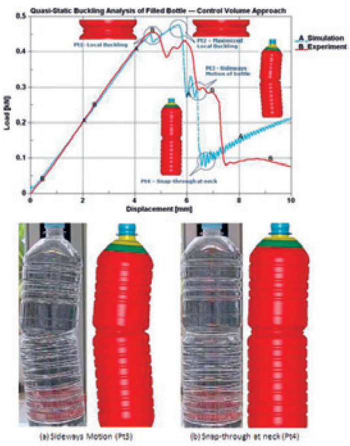

Fig. 3: Structural Response of Filled Bottle

- CV approach: the simplest, most accurate and computationally least expensive method to account for the compressibility effect. Since the mass of the liquid cannot be modelled with this approach, inertial effects cannot be accounted for.
- SPH approach: this accounts for the inertial effects, but fails to account for the compressibility effect accurately, due to a non-realistic gap between the walls of the bottle and water (SPH particles). In addition, modelling of both air and water with SPH is infeasible.
- ALE approach: computationally the most expensive. The existence of potential leak-

age problems and the extreme sensitivity of a parameter (PFAC) to fluid-structure coupling lead to an unreliable result.

Since fluid compressibility is the most important effect for predicting the correct buckling load in a quasi-static buckling analysis, the CV approach is considered for top-load simulation of the filled bottle. The initial slope and the buckling load fit in nicely with the test results (Fig. 3). Also the post-buckling shape of the filled bottle from simulation resembles the test (Fig. 3). The post-buckling regime is influenced mostly by the missing inertial effects in the CV approach.

approach where the bottle is physically moved in reality, and the load-body approach where an imaginary observer is sitting on top of the bottle and inertial loads are calculated and applied on a motionless bottle) were each evaluated. Since in reality liquid (SPH particles) inside a rotating bottle experiences inertial forces only after a certain amount of time once it also starts rotating, the full-rotation approach was preferred to the load-body approach in order to account for this effect naturally.

As the time taken for a single bottle to undergo such a fast and dynamic process is only 803 ms, it was very hard for the cus-

normally expected due to the outward movement of the particles once the bottle starts to rotate with the table (Fig. 6).

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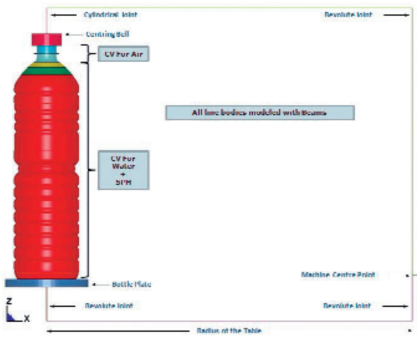

Fig. 4: Model setup for process simulation

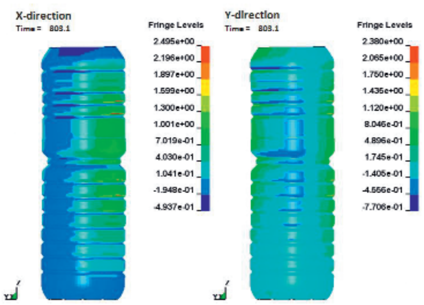

Fig. 5: Deformation of the bottle body in mm

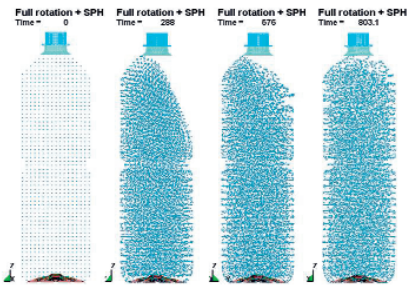

Fig. 6: Movement of SPH particles in the bottle (body hidden)

Process simulation in the labeller

The goal of process simulation is not to check the bottle labelling procedure, but to predict the deformation behaviour of the bottle due to the inertial forces involved (centrifugal and coriolis). The bottle experiences these forces due to the two kinds of rotation (with respect to the table and with respect to itself) during the labelling process.

Since the inertial forces acting on the bottle are governed mainly by the mass of the water, idealisation of water with SPH particles was considered so as to accurately account for the inertial effects of water. Moreover CVs for both air and water were retained in the model setup (Fig. 4) to account accurately for the compressibility effects of air and water respectively.

Concerning the kinematics, or how the two rotations are described (the full-rotation

tomer to obtain any test data about the deformation behaviour of the bottle concerned. However, for any machine to be termed reliable it has to fulfil certain requirements, which serve as a means for validating the simulation results. The major requirements that need to be met are as follows:

- the bottle should not be thrown out of the labeller (i.e. machine usage guaranteed).
- the bottle is not allowed to buckle at any point in time within the labeller (i.e. usability of the bottle is guaranteed).
- permissible lateral deformation (Fig. 5) of the bottle for proper label location is very small (i.e. promotion of brand quality guaranteed).

In addition, SPH particles represent an inclined free surface of the liquid, which is

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