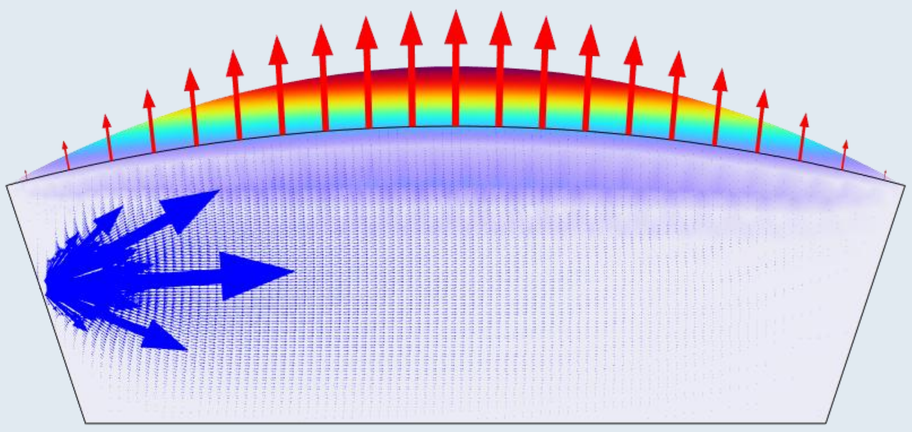

Coupled CFD-Structural Mechanics Simulation Of Deformation In Non-Rigid Polypropylene Food Packaging

Numerical and experimental study of deformation in polypropylene food trays under air injection using coupled CFD–structural mechanics modelling.

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Abstract

Understanding deformation in non-rigid food packaging is critical for ensuring product safety during processes involving pressurization such as sterilization. Polypropylene (PP) trays sealed with thin lidding films are especially vulnerable to rupture at the heat-seal zone under internal pressure buildup [1]. This study focuses on simulating film displacement during controlled air injection into PP trays using a coupled CFD and Structural Mechanics approach. A 2D model of an empty PP tray was developed in COMSOL Multiphysics® 6.3 to simulate airflow and film deformation under inlet flow rates of 0.10, 0.15, and 0.60 L/min. The model predicted the maximum displacement of the PP film at the time of rupture around 8–11 mm. The model reproduced the experimental displacement of the PP film with a normalized RMSE of 8.52%, which is in close agreement with the experimental value of around 10 mm. This study provides a simplified fluid-structure interaction model dedicated to prediction of PP film deformation under pressurized air.

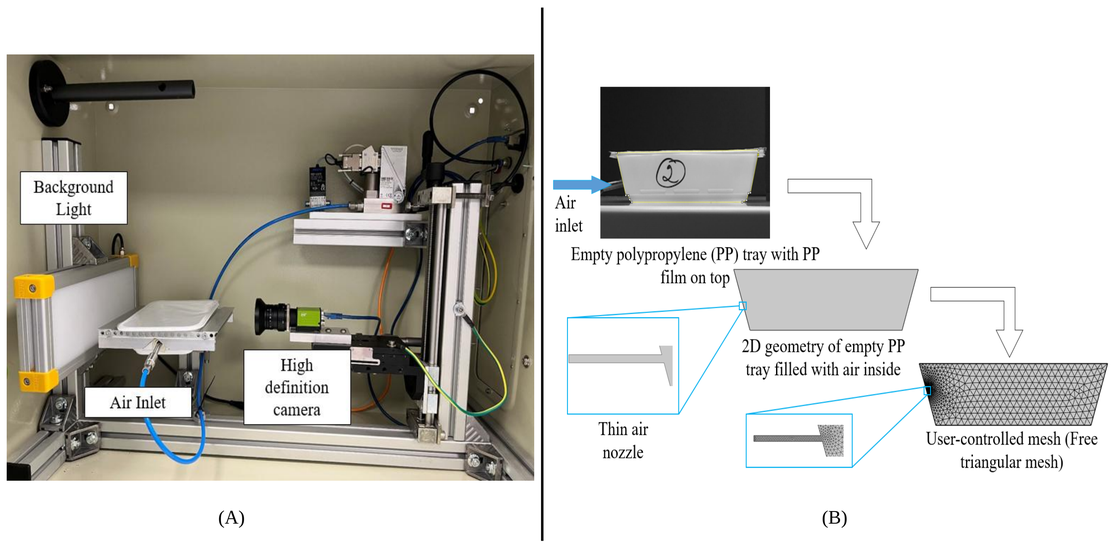

Figure 1. (A) Experimental setup of the air injection system.(B) Polypropylene (PP) food tray with PP film on top and meshing in COMSOL Multiphysics® 6.3.

Methodology

- Air-injection experiments were performed on sealed PP trays (Figure 1(A)). Compressed air was introduced through an inlet at constant flow rates of 0.10, 0.15, and 0.60 L/min.
- A high-resolution camera (Go, JAI Ltd., Japan) recorded the film response at 1 fps; rupture was identified by a sudden pressure drop and visible failure at the heat-seal.
- A 2D CFD–Structural Mechanics model was developed (Figure 1(B)). The compressible Navier–Stokes equations for laminar flow of air coupled to conservation of momentum for a deformable solid (PP film) were solved. Film displacement at the tray was quantified via image analysis.

Results

- The simulation results demonstrated the model's ability to predict film displacement (Figure 2) during air injection.
- Using best-fitted mechanical properties (Youngs modulus and Poisson ratio), as reported by [2], at 0.10 L/min, the maximum simulated displacement was 8.66 mm at 94 s (10.00 ± 1.05 mm experimentally). At 0.15 L/min, displacement reached 10.18 mm at 83 s (10.80 ± 0.27 mm experimentally). At 0.60 L/min, the simulation produced 11.24 mm at 25 s (10.70 ± 0.30 mm experimentally).

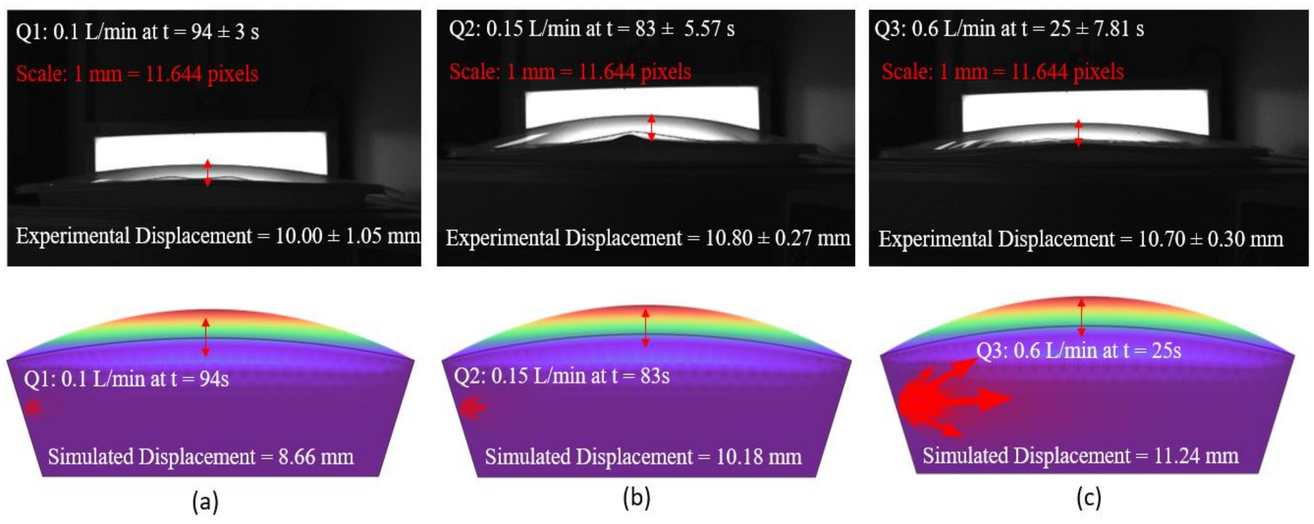

Figure 2. Experimental displacement images and 2D simulated displacement images of PP film at the time of rupture for (a) Q1 : 0.1 L/min, (b) Q2 : 0.15 L/min, (c) Q3 : 0.6 L/min.

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