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Modelling deformation and fracture in confectionery wafers

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Abstract

The aim of this research is to model the deformation and fracture behaviour of brittle wafers often used in chocolate confectionery products. Three point bending and compression experiments were performed on beam and circular disc samples respectively to determine the 'apparent' stress-strain curves in bending and compression. The deformation of the wafer for both these testing types was observed in-situ within an SEM. The wafer is modelled analytically and numerically as a composite material with a core which is more porous than the skins. X-ray tomography was used to generate a three dimensional volume of the wafer microstructure which was then meshed and used for quantitative analysis. A linear elastic material model, with a damage function and element deletion, was used and the XMT generated architecture was loaded in compression. The output from the FE simulations correlates closely to the load-displacement deformation observed experimentally.

Keywords: foam; x-ray tomography; brittle fracture; finite element; damage modelling

1. Introduction

Wafers are often used in chocolate confectionery products. In large scale food production, of confectionery wafers with cream layered fillings, the cutting process is automated and one of the most crucial stages in the manufacturing. This often results in distorted cuts and broken wafers, leading to a loss of product and hence reduced processing efficiency. There is a need to develop models for predicting deformation and fracture of the wafers in such products so that problems arising during large scale processing can be eliminated. In this work, a comprehensive analysis of the wafer is being performed, using a combination of experimental, analytical and numerical techniques.

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2. Materials & Methods

The wafer is made by baking between two hot plates, a liquid batter which consists primarily of wheat flour and water, with trace amounts of other ingredients. During the baking process most of the moisture evaporates, resulting in a porous foamed cellular structure. The faces of the wafer sheet that were in contact with the hot plates are less porous than the microstructure at the centre of the wafer sheet. The two denser faces of the wafer sheet are designated as the 'wafer skin' while the less dense region is referred to as the 'wafer core'.

Mechanical testing was performed using an Instron 5543 at a constant speed with a 1 kN load cell at ambient conditions of 20°C and 50% humidity. The wafer sheets were tested under compression and bending, from which 'apparent' stress-strain curves were derived. Circular discs of 40 mm diameter were stacked on top of each other to test the stack size, reeding orientation and rate dependency of the wafer. For the three point bending, single wafer specimens of 120 mm length and 15 mm width were used. Single square wafer sheets of size 7.5mm were later tested in compression for comparison with the in-situ SEM and XMT compression experiments.

The wafer sheet was examined with an optical microscope and Scanning Electron Microscope to determine the wafer dimensions as well as to characterise the internal microstructure. In-situ compression and bending experiments were performed on the SEM so that the actual deformation could be observed within the microstructure of the wafer.

A Phoenix X-ray v|tome|x computerized tomography system was used to scan the wafer and produce a stack of image slices. They were then used to generate a 3D volume of the wafer microstructure using Avizo software [2]. With this virtual wafer, it was possible to accurately determine the porous volume fraction of the overall wafer and the porosity distribution throughout the wafer. The reconstructed 3D volume was meshed with tetrahedral elements and then exported to the finite element software, Abaqus [3], to perform a quantitative analysis. A static in-situ XMT compression test was performed to characterise the three dimensional deformation of the wafer.

The initial numerical model was developed to verify the analytical models. A three dimensional model of the wafer with a simple geometry was generated in CAD software and imported into Abaqus for analysis. The second FE model used the meshed 3D volume obtained from XMT to simulate the compression of the exact architecture of the wafer. An elastic-plastic material model was used to represent the solid cell walls of the wafer. A damage criterion was implemented to the material model which degenerates and then deletes elements. The parameters for damage initiation and damage evolution were critical plastic strain and fracture energy respectively. The model was compressed between two rigid bodies which represented the compression plates.

3. Results & Discussion – Experimental Testing

The wafer deformation was shown to be independent of speed over three orders of magnitude and thus a single wafer sheet could safely be compressed at low speeds. Figure 1a) shows the 'apparent' stress-strain response of a wafer stack loaded in uni-axial compression. The three distinct regions of deformation, i.e. the elastic, plateau and densification zones are observed. The elastic modulus was determined from the initial linear section of the stress-strain curve of a single square wafer sheet. This value was found to be 4.3 MPa.

Figure 1b) shows the brittle load-deflection response obtained from the three point bending experiments. The apparent flexural modulus was calculated using beam theory and was found to be 980 MPa. This value was considerably higher than the compression modulus and implied that the wafer was a sandwich structure. Thus, the main deformation in bending occurred at the stiffer skins while in compression the porous core was the site of initial damage.