A Comparison of the Mechanical and Sensory Properties of Baked and Extruded Confectionery Products

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Abstract. Traditional baking is the most common way of producing confectionery wafers, however over the past few decades, the extrusion process has become an increasingly important food manufacturing method and is commonly used in the manufacturing of breakfast cereals and filled snack products. This study aims to characterise products made via each of these manufacturing processes in order to understand the important parameters involved in the resulting texture of confectionery products such as wafers. Both of the named processes result in brittle, cellular foams comprising of cell walls and cell pores which may contain some of the confectionery filling. The mechanical response of the cell wall material and the geometry of the products influence the consumer perception and preference. X-Ray micro tomography (XRT) was used to generate geometry of the microstructure which was then fed to Finite Element (FE) for numerical analysis on both products. The FE models were used to determine properties such as solid modulus of the cell walls, Young's modulus of the entire foam and to investigate and compare the microstructural damage of baked wafers and extruded products. A sensory analysis study was performed on both products by a qualified sensory panel. The results of this study were then used to draw links between the mechanical behaviour and sensory perception of a consumer. The extruded product was found to be made up of a stiffer solid material and had a higher compressive modulus and fracture stress when compared to the baked wafer. The sensory panel observed textural differences between the baked and extruded products which were also found in the differences of the mechanical properties of the two products.

EXPERIMENTAL AND FINITE ELEMENT ANALYSIS

Confectionery wafers and extruded snacks are usually brittle, cellular materials. Consumers base their perception and appreciation of such foods on characteristics such as crispness or crunchiness of the food. A large proportion of experiments and studies[1-4] appear to use the fundamental mechanical properties, namely Young's Modulus and critical stresses, as a mean to characterise and compare the mechanical properties of crispy food products. It is therefore a general consensus that both 'crispy' and 'crunchy' sensations relate to the fracture properties of food materials[5]. The quality of a food product can be defined by its sensory characteristics which can be influenced by shape, size, colour, and textural properties. It is therefore of great interest to study the properties of food products from a mechanical and textural perspective.

Mechanical tests and imaging techniques such as X-ray Micro tomography were used to study the effect of the microstructure on the material properties of baked wafers and extruded products. Compression tests were performed on circular specimens (diameter (d) = 40 mm, thickness (t) = 2.3 mm) of baked wafer and a standard extruded product in the shape of hollow tubes (outer diameter (d_o) = 12-16mm and inner diameter (d_i) = 7-9mm). The force-displacement data from the compression tests was converted into stress and strain values by using the cross-sectional area and change in sample height. FIGURE 1 shows a comparison between the typical stress-strain responses of baked wafer and confectionery wafers under axial compression up to the fracture. Fracture stress of the foam (σ^*) was also obtained from the stress-strain curves of both products. The compressive response of the extruded tube shows a significant amount of jaggedness in the stress-strain curve when compared to the baked wafer suggesting that the extruded product may be perceived to be a crispier material. The axial compressive modulus of the baked wafer and the extruded tube was measured from the initial region of the curves in Fig. 1 and were found to be 4.7 ± 0.4 MPa and 44.6 ± 9.4 MPa. The fracture stress of the extruded tube was found to be higher at 0.6 ± 0.05 MPa compared to the fracture stress of 0.39 ± 0.05 MPa found from the stress-strain response of the baked wafer. The density measurements of the two types of products showed that the relative density of both products was within experimental scatter of each other with an average relative density of 0.22 and hence a porosity of approximately 78%.

XRT was used to create FE models of the actual microstructure of the extruded tube, Fig 2. Compressive loading was applied to these models and a parametric study was performed in ABAQUS in order to determine the solid material modulus (E_{solid}) of the extruded product by obtaining an FE foam modulus which matched the experimental foam modulus of 44.6MPa. FIGURE 3 shows the results of the inverse study. The solid modulus of the extruded tube was approximated to be 320 MPa, whereas in a previous study, E_{solid} of the baked wafer was estimated to be 180MPa[6].

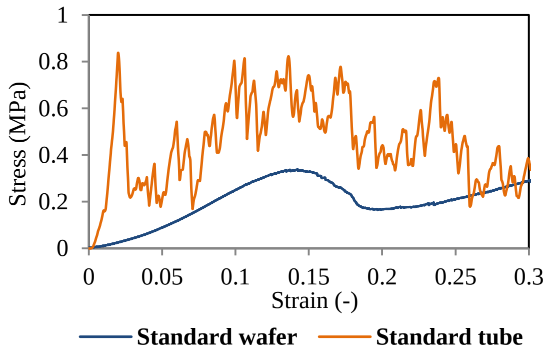
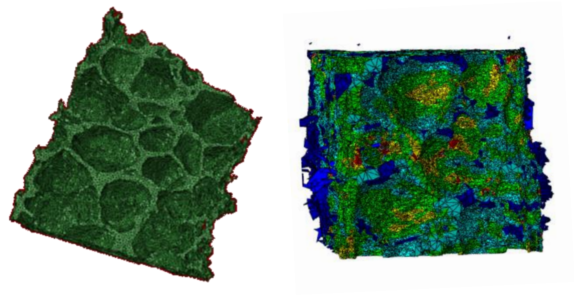


FIGURE 1 – Typical stress-strain response of a Baked wafer and Extruded tube



(a) (b)

FIGURE 2 – Finite Element Model of a section of the Extruded Product (a) Tetrahedral mesh (b) Contours on the FE model from a rotated view

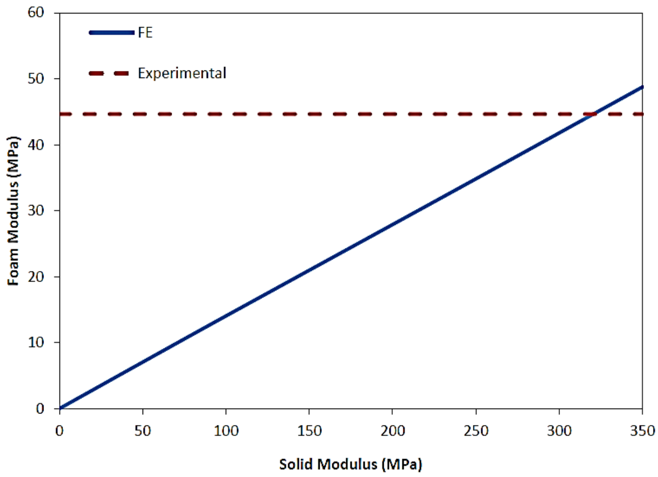


FIGURE 3 – Effect of solid modulus on the foam modulus of the standard tube

The Ashby and Gibson analytical solution[7], Eqn. 1, was used to estimate the value of φ based on the solid material moduli (E_{solid}) values of the baked wafer and standard extruded tube. From the range of E_{solid} values from φ = 0 i.e. closed cell foam and φ = 1 i.e. open cell foam, the standard tube was found to be a mix of open and closed cells with φ = 0.4, whereas the baked wafer was found to be an open cell foam with φ = 1 shown by the dotted lines on Fig 4.

$$\frac{E^*}{E_{solid}} = \varphi^2 \left(\frac{\rho_{foam}}{\rho_{solid}}\right)^2 + (1-\varphi)\left(\frac{\rho_{foam}}{\rho_{solid}}\right) \qquad \textbf{(Equation 1)}$$

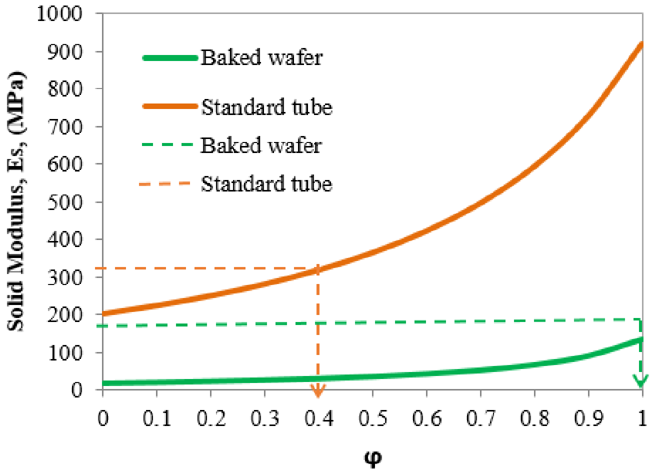


FIGURE 4 – Estimating a value of φ for known solid modulus of baked wafer and standard tube

SENSORY PROFILING OF CONFECTIONERY PRODUCTS

A sensory analysis study was conducted on the baked wafer and extruded tube by trained a sensory panel at Nestle NPTC Confectionery, York. The sensory attributes of hardness, noisiness and crumbliness of the extruded tube were given higher scores by the sensory panel when compared to the baked wafer whereas the bubble size and aeration scored similarly. The sensory attribute of hardness was defined as 'the strength required to break the product' which can be compared to the mechanical property of fracture stress and the aeration of the product can be compared to the porosity of the products. The higher hardness score of the extruded tube and the similar aeration scores are in agreement with the higher fracture stress of the extruded tube and similar porosity results of the products.

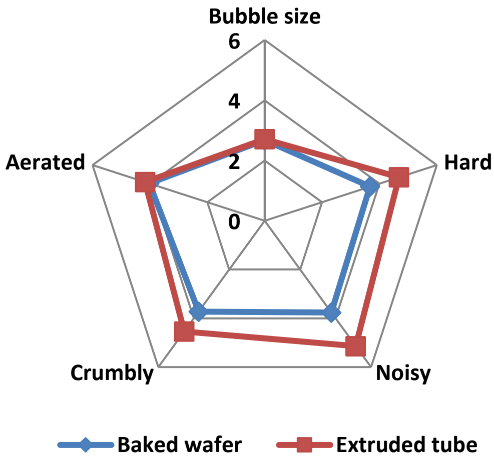


FIGURE 5 – Sensory Profile of Baked Wafer and Extruded tube

CONCLUSIONS

The comparison of the mechanical data of the baked wafer and extruded product showed that the latter was found to be a stiffer material with a higher fracture stress which was in agreement with the sensory perception of hardness of the extruded product. From the FE model created from the XRT scans of the extruded tube, the solid material modulus was found to be higher than the previously determined solid modulus of the baked wafers. Additionally, the two products were found to be different in terms of the material distribution in their cellular microstructure. This explains the differences in the foam modulus of the two products despite the similar relative densities. The sensory analysis data showed that the sensory panel was able to detect textural differences between the baked and extruded products which were also observed in the differences of the mechanical properties of the two types of products. The FE model of the extruded tube can be used to simulate damage in the model in order to better understand the microstructural behaviour of the extruded tube under mechanical loading.

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REFERENCES

1. Sandoval, A. J., Chaunier, L., Courcoux, P., 2008, "*Bulk Mechanical Behavior of Commercial Particle Food Foams,*" Journal of Texture Studies, Vol 39(4) pp. 405-425.

2. Arimi, J., Duggan, E., O'sullivan, M., 2010, "Effect of Water Activity on the Crispiness of a Biscuit (Crackerbread): Mechanical and Acoustic Evaluation," Food Research International, Vol 43(6) pp. 1650-1655.

3. Roudaut, G., Dacremont, C., and Meste, M. l., 1998, "INFLUENCE OF WATER ON THE CRISPNESS OF CEREAL-BASED FOODS: ACOUSTIC, MECHANICAL, AND SENSORY STUDIES," Journal of Texture Studies, Vol 29(2) pp. 199-213.

4. Ashby, M. F., 2006, "The Properties of Foams and Lattices," Philosophical Transactions.Series A, Mathematical, Physical, and Engineering Sciences, Vol 364(1838) pp. 15-30.

5. Luyten, H., J PLIJTER, J., and Van Vliet, T., 2004, "Crispy/crunchy Crusts of Cellular Solid Foods: A Literature Review with Discussion," Journal of Texture Studies, Vol 35(5) pp. 445-492

6. Mohammed, I.K, Charalambides, M. N., Williams, J.G., Rasburn, J., 2012, 'Modelling the deformation of a confectionery wafer as a non-uniform sandwich structure', Journal of Material Science, Vol 48, pp2462 – 2478.

7. GIBSON, L. J. & ASHBY, M. F. 1999. Cellular solids: Structure and properties, Cambridge University Press.

8. Mohammed, Idris, Kevin, Charalambides, M. N., Williams, J. G., 2013, "Modelling the microstructural evolution and fracture of a brittle confectionery wafer in compression," Innovative food science and Emerging Technologies, Vol 24, pp. 48-60.