MEASURING PRESSURE IN APPLE CONTACTS

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ABSTRACT
A large number of apples are wasted each year due to bruising. A novel ultrasonic technique has been used to assess apple contacts to provide a greater understanding of the bruising process and to provide validation for an FE apple model which will be used as a design tool to optimise apple packaging to reduce the advent of bruising.

INTRODUCTION
It has been calculated that 8-10% of apples are wasted each year due to damage occurring during transportation from the orchard to the supermarket [1] and the major cause of this wastage has been identified as being bruising [2]. The physical loads that an apple experiences mainly affect the membrane systems of individual cells, which make up the apple flesh. These membranes essentially keep things separate, but when damaged are no longer able to do this and the reaction caused by mixing of enzymes causes the brown coloration associated with a bruise.

The aim of the work outlined here was to use a novel non-invasive ultrasonic technique to study static apple contacts, as experienced, for example, during storage in bulk bins, to determine the area of contact and interfacial pressure. The nature of the resulting bruising was also examined in order to find load thresholds at which unacceptable damage occurs. The ultrasonic results were then used to validate the output from a finite element (FE) model of an apple, which will ultimately be used as a design tool for improving apple packaging and reducing waste.

ULTRASONIC MEASUREMENTS
Ultrasonic measurements were carried out using a procedure defined previously [3]. An ultrasonic wave is focused on the apple contact. It passes through regions of asperity contact and is reflected back at air gaps. A reflection coefficient, \( R \), is defined as the proportion of the signal amplitude reflected from the interface.

It has been shown that the reflection coefficient can be defined in terms of the interfacial stiffness, \( K \), using a spring model of the interface [4]:

\[
|R| = \frac{1}{\sqrt{1 + (2K/\omega z)^2}}
\]

where \( \omega \) is the angular frequency (= \( 2\pi f \)) of the ultrasound wave and \( z \) is the acoustic impedance (the product of the wave speed and density). Tests at low pressures using typical machined surfaces showed that the contact pressure is proportional to the interfacial stiffness [5]. This means a simple calibration can be carried out to relate the two parameters.

Ultrasonic scans were carried out of an apple/perspex interface. Perspex was used as it is typical of materials used to manufacture apple storage bins. A compressed spring arrangement was used to apply load and the interface was then scanned through the perspex.

A reference measurement was taken at a point away from the contact to determine the proportion of the ultrasonic signal lost due to attenuation in the perspex. The reflected pulses from the apple/perspex contact were then divided by the reference recording to obtain reflection coefficients. These were converted to contact pressure using a calibration approach [3].

Golden Delicious apples were used for the tests. This variety was chosen because it's pale skin means bruising is more evident. Loads used in the tests ranged from 2N to 100N. These are typical of loads seen by apples in bulk storage bins [6].

An example of an ultrasonic scan at 50N is shown in Figure 1. The maximum pressure was at the centre of the contact, and the pressure falls away towards the edge. The maximum stress in the contact remains at a level of around 0.5MPa for all loads and clearly represented the failure stress of the apple flesh.
The failure threshold of 100mm$^2$ is a value used in industry for determining which apples should be discarded due to damage. The results shown indicate that at loads above around 35N, the contact area will be over this threshold. This is a conservative estimate, though, as the contact area will probably be larger than the actual bruise area.

FINITE ELEMENT ANALYSIS

In order to use the geometry of an actual apple in the FE modelling, a laser scan was created of an apple, which was then imported into ANSYS LS-DYNA software to create a mesh. The volume was free meshed with tetrahedral elements. It was found that a density of 17000 elements was sufficient to accurately represent the apple geometry.

Isotropic properties were assumed for the apple flesh. A Young’s modulus of 4MPa was used, as determined previously for Golden Delicious flesh [7]. Linear elastic material properties were used, and while this is not valid for apple flesh, this is how it has been modelled in previous work and so allows comparisons to be made. Future work is focusing on using more appropriate properties and structure for the apple model.

To replicate the loading in the ultrasonic apparatus, the apple was placed between two plates. The bottom plate was fixed and the top plate was displaced to achieve the desired normal load on the apple.

The contact pressure from FE analysis for an apple/perspex contact at 60N is shown in Figure 4. As can be seen the maximum contact pressure is in the centre of the contact and reaches a value of just over 0.7MPa.

CONCLUSIONS

A novel ultrasonic technique has been used to characterise areas and pressures in apple to perspex contacts. The results compare well with those from finite element modelling using the geometry of an actual apple, despite the assumptions made. Failure stresses predicted using both techniques are similar to values determined using mechanical tests (0.4-0.51MPa [7]). The FE model has a number of simplifications, including isotropic properties, but with improvements to vary apple flesh properties and introduce a core and skin it would have the potential to be used as a design tool for assessing packaging material and designs to help reduce the likelihood of damage occurring.

REFERENCES