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Research note

Effect of size and shape on modulus of deformability

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Abstract

The effect of size and shape on the modulus of deformability was investigated and the analysis was extended to irregularly shaped cross-sections. Cylindrical specimens of raw potatoes with diameters (D) of 8.6 and 12.4 mm, heights (L) $L = D$ and $L = D/2$ and water activity 0.94 were used as test materials. Their modulus of deformability was evaluated from a compression test. Multiplying the linear region moduli obtained from the stress–strain curves, by a modification factor of $D/4L$ yielded a size-independent modulus. $D/4L$ represents the ratio of the stress-bearing cross-sectional area that accounts for expansion to the stress-free surface area that accounts for material compressibility. The concept was further applied to samples with irregularly shaped cross-sections. Force–deformation data for these samples were converted to stress–strain data by using the cross-sectional area of the silhouettes of the samples. Modulus of deformability was evaluated from the stress–strain data and modified by multiplying with $D_f/4L$ where D_f is the ferret diameter of the stress-bearing cross-section. Moduli of deformability for the irregularly shaped samples were found to behave similar to their cylindrical counterparts. This type of analysis should help to obviate the need for any other correction procedure and make comparative evaluation of deformation moduli more meaningful.
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Keywords: Modulus of deformability; Elastic modulus; Shape factor

1. Introduction

Texture is an important quality parameter that determines the identity of the material and greatly affects consumer preference. However, most metrics of texture measurements show dependence not only on processing and handling techniques and/or ingredient combinations, but also on irregularities in shapes, sizes and curvatures that is inherent to most food products. As a result, a variety of stress–strain curves are reported in the literature for numerous products made under the same processing conditions and handled the same way (Canet & Sherman, 1988).

Rubbery materials and biological tissues have a Poisson ratio of 0.5, while cellular solids have Poisson ratios between 0.1 and 0.4 (Lakes, 1987). The effect of size and shape on stress–strain behavior of various visco-elastic food materials (Poisson ratios in the range of 0.3–0.5) have extensively been studied with inconclusive results among different studies on the same material (Kaletunc, Normand, Jhonson, & Peleg, 1991; Ak & Gunasekaran, 1992; Abbott & Lu, 1996; Hort & Le Grys, 2000). Shape and size are also expected to be important in texture-fingerprinting of cellular foods such as breakfast cereals and snacks. These materials have different expansion ratios due to ingredient formulation, moisture content, processing conditions, and different shapes due to forming techniques, which also affect their microstructure. Texture–microstructure relationship for cellular foods has been a major area of interest, but in such cases comparative assessment of texture requires identification of texture parameters that are independent of size and shape.

The modulus of deformability is an important textural property, since it can be related to crispiness and cruchiness in cellular foods such as breakfast

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cereals, snack foods (Guraya & Toledo, 1996; Segnini, Dejmek, & Oste, 1999) and nuts (Saklar, Ungan, & Katnas, 1999), or it can be related to stiffness in the case of visco-elastic materials like cheeses (Visser, 1991). However, most food materials do not obey the rules of linear visco-elasticity, and thus they either do not have a well-defined linear region or a very short one (Mohsenin & Mittal, 1977), and the slope of the stress–strain curve in this linear range is termed as the modulus of deformability (Rebouillat & Peleg, 1988). The importance of the size of the test specimen on the elastic range has been emphasized and it has been suggested that the height of the specimen should be equal to or less than its diameter, otherwise reproducibility and reliability of compression tests will decrease due to buckling (Shaw & Young, 1988). The type of fracture the specimen undergoes is also highly related with its length to diameter ratio (Luyten, Van Vliet, & Walstra, 1992). Surface smoothness of the sample plays an important role as well on the reliability of modulus of deformability measurements since rough surfaces cause the area of application of force to vary during the compression test (Chu & Peleg, 1985).

The objective of this study was to assess the effect of size and shape of on the modulus of deformability for a material with Poisson ratio in the range for cellular solids, and for which the effects of micro structural failure would be minimal within the elastic range. A modification factor that would yield a size and shape independent modulus is expected to aid in distinguishing texture–microstructure relationships for cellular foods. A method was developed that involves evaluation and integration of a modification factor with respect to material size and shape into the assessment of modulus of deformability for specimens with smooth, irregularly shaped cross-sections. Cross-sectional area of the silhouettes of these samples was used to evaluate the stress–strain data from the force–deformation data.

2. Materials and methods

2.1. Materials

Idaho baking potatoes purchased from a local market between November 2001 and August 2002 were used. Moisture content of the potato samples were between 88.3 and 91.5 g/100 g (wb), measured by drying in an oven at 103 °C for 24 h (AACC, 1995).

Raw potato tissue was selected as the test specimen because it was amenable to preparation of specimens in a variety of sizes and shapes, had a fairly uniform moisture distribution and tissue orientation making it shrink uniformly during adjustment of water activity, and thus maintain its shape. A smooth, flat surface could easily be obtained during sample preparation, which was further preserved during water activity adjustment. Also, upon adjustment of water activity, potato tissue yielded a relatively uniform model system with a Poisson ratio of 0.2, in the range for cellular solids.

2.2. Sample preparation

Test samples were prepared in cylindrical and irregular shapes. Cylindrical samples were obtained using cork borers with diameters (D) of 8.6 and 12.4 mm, respectively. The height of the samples (L) were $L = D$ and $L = D/2$. Irregularly shaped samples were prepared using the 12.4 mm cork borer for samples with height $L = D/2$, and then cutting the cylindrical sample randomly on its cross-section to obtain an irregularly shaped smooth surface.

Samples were kept at a constant water activity of 0.94 (supersaturated KNO_3) and 25 °C until their moisture content was in the range of 59–71 g/100 g (wb). Height and diameter of the samples were measured by a caliper prior to the compression test (Table 1). Fractional shrinkage calculated from the means of measurements reported in Table 1 was in the range of 0.15–0.17 with a standard deviation of ± 0.02–0.03 in diameter, and 0.15–0.16 with a standard deviation of ± 0.02–0.04 in height. Aspect ratio (D/L) for all samples was similar to its value before adjustment of water activity.

The height of specimens with irregularly shaped cross-sections was measured, and the silhouette of the compression surface was traced. Images of these silhouettes were scanned to the computer, and then the area and ferret diameter of the images were evaluated (SigmaScanPro 5.0, Jandel Inc., San Rafael, CA). Area of the silhouettes is equivalent to the sum of calibrated pixels units of their images. Ferret diameter is defined as the diameter of the circle having the same area as the irregularly shaped image. Compressive stress was calculated dividing the measured compressive force by the area of the silhouettes.

2.3. Compression tests

Static compression tests were performed at 25 °C in a DMA-7e (Perkin Elmer) using the 15 mm circular cup-and-plate arrangement. Specimens were compressed up to 2000 mN at a rate of 100 mN/min, and stress–strain curves were obtained. The elastic range of the stress–-strain curve for each specimen was determined, and the modulus of deformability was evaluated. The engineering strain range for water activity adjusted raw potato specimens was 0.02–0.04.

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