Examining the Effect of Dough Matrix and Bubbles on the Properties of Dough using Low-Intensity Ultrasound

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ABSTRACT

The appearance and texture of many cereal products largely depends on the manner in which gas cell structure is created in the dough during processing. Low-intensity ultrasound is a useful cereal chemistry tool because of its sensitivity to the presence of bubbles within the dough's viscoelastic matrix and to the properties of the matrix itself. Measurements of ultrasonic velocity and attenuation over a wide frequency range have allowed us to gain new insights into the structure, properties and dynamics of dough systems. At low frequencies, the properties of the dough as a whole are interrogated, so that an analysis of how wheat flour strength affects dough properties is feasible. At low MHz frequencies, the mechanical spectrum is dominated by bubble resonance. In this region, we observe Ostwald ripening of bubbles within breadmaking doughs that have been made without leavening agents, a novel observation dependent on ultrasound's ability to probe bubbles inside opaque food systems. At higher frequencies, ultrasound probes dough matrix properties, revealing a structural relaxation in the nanosecond time range that is likely associated with conformational changes in gluten proteins. Therefore, ultrasound has the potential to provide new information on dough properties to allow better prediction of the gas cell structure of the resulting loaf of bread.

INTRODUCTION

Bread making has been viewed as a series of aeration stages: bubbles created during mixing are inflated with carbon dioxide during proofing before being modified and set during baking to form the aerated cellular structure of the bread crumb (Campbell et al 1998). Low-intensity ultrasound is particularly sensitive to the presence of bubbles in a viscoelastic matrix, and so is a useful tool for examining the creation, growth and setting of bubbles in the processing of dough into bread (Scanlon et al 2008). Because ultrasonic techniques will characterize material properties over a wide range of frequencies, various length scales can be probed, with the result that the frequency dependence of the phase velocity and attenuation coefficient provides valuable information on the mechanical properties and structure of soft materials (Strybulevych et al 2007). The objective of this paper is to illustrate the use of low-intensity ultrasound for investigating the effects of gas bubbles and matrix elasticity on the properties of viscoelastic bread doughs.

MATERIALS AND METHODS

Dough Preparation

Various flours covering a range of dough strengths were prepared by straight grade milling. All doughs were prepared using short-time mechanical dough development from just flour (100 g), salt (2.4 g) and water (various amounts to give optimum dough handling characteristics). Doughs were mixed at atmospheric pressure or under vacuum (the latter to reduce the number of bubbles in the dough).

Dough Analyses

Dough densities were measured using Archimedes' principle. Pulsed transmission techniques were used to measure the ultrasonic velocity and attenuation of the dough by placing the dough sample directly in contact with two transducers. Pairs of transducers with central frequencies from 50 kHz to 20 MHz were used to probe dough properties over almost three decades in ultrasonic frequency. Dough sub-samples of various thicknesses were analysed using either time-domain or Fast Fourier Transform techniques.

RESULTS AND DISCUSSION

The Strong Effect of Bubbles on Dough Properties

As pointed out in Scanlon et al (2011), the most striking aspect of the frequency dependence of the phase velocity and attenuation coefficient is the resonance peak that defines three distinct regions of the mechanical spectrum of dough. At low frequencies, ultrasonic wavelengths are large compared to bubble size, and dough behaves like an effective medium where both bubbles and dough matrix affect the measured ultrasonic parameters. At higher frequencies (low MHz), near the resonance frequency of the bubbles in the dough, the attenuation coefficient and phase velocity undergo substantial changes as a function of frequency. At high frequencies, the phase velocity attains an almost constant value that is associated with the properties of the dough matrix.

By mixing dough under vacuum, thereby virtually eliminating bubble nucleation, we can show that it is the bubbles in dough that are responsible for the attenuation peak and the drastic changes in velocity (Fig. 1). In vacuum-mixed doughs (open symbols), the attenuation peak almost disappears (note log scale) and the velocity is almost invariant across the whole of the frequency range, reflecting the properties of the dough matrix. The data are qualitatively similar to the velocity and attenuation behaviour of bubbly liquids near the fundamental bubble resonance. The solid lines show theoretical calculations for water with the same bubble volume fraction (ϕ) as the air-mixed doughs.

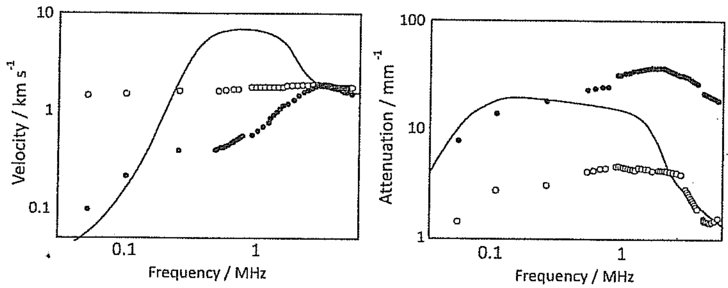

Fig. 1. Frequency dependence of velocity (left) and attenuation (right) for dough made from CWRS wheat flour mixed in air (closed symbols) and under vacuum (open symbols) with theoretical lines for 8.5% (by volume) bubbles in water

Low Frequency Measurements of Dough Strength

By performing measurements at 50 kHz (where the ultrasonic wavelength is much larger than the sizes of the bubbles), ultrasound probes the properties of the "composite" material comprised of bubbles and dough matrix. For doughs made from different flours, a strong positive relation between ultrasonic velocity and dough strength as measured by the alveograph work index, *W*, is observed (Fig. 2) with r^2 = 0.73. Because 4g – 7g of dough suffice for ultrasonic evaluations, low frequency ultrasound may be a useful dough strength screening assay for samples at an early stage of wheat breeding programs where sample size is limiting.

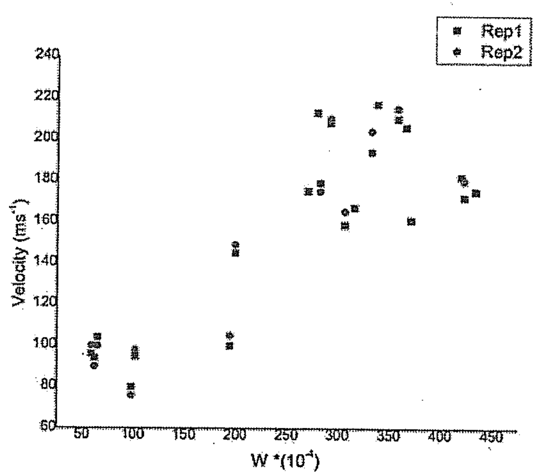

Fig. 2. Relationship between ultrasonic velocity and alveograph *W* parameter for doughs made from flours of different strength

Examining Bubble Evolution in Doughs

If ultrasonic measurements are performed at frequencies close to bubble resonance, measured ultrasonic parameters are keenly sensitive to changes in the bubble distribution (Leroy et al 2008). Disproportionation of bubbles is known to occur in doughs that have been made without yeast (van Vliet 1999) thereby altering the bubble size distribution. To examine how ultrasonic measurements were affected by changes in the bubble distribution, the attenuation coefficient in the vicinity of the attenuation peak was measured at 2 min intervals in dough subsamples excised from the dough piece at various times after mixing (Fig. 3). The peak in attenuation decreases with time and shifts to a lower frequency (longer wavelength); both phenomena are consistent with the growth of larger bubbles at the expense of smaller ones as the total bubble surface area decreases due to diffusion of gas from small to large bubbles within the dough (van Vliet 1999).

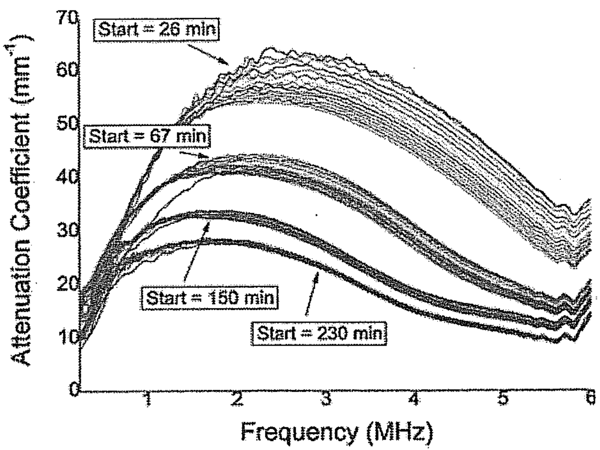

Fig. 3. Time-dependent changes in attenuation of dough sub-samples excised from the dough piece at various post-mixing times

High Frequency Measurements of Molecular Relaxation

At high frequencies, short wavelength ultrasound is sensitive to events occurring in the dough matrix (Fig. 4). We used a classical ultrasonic relaxation model (Litovitz and Davis 1965), with parameters shown in the sidebar to the figure, to understand how the frequency dependence of velocity and attenuation is influenced by molecular relaxations (shown as thin line fits to high frequency data). The model is not intended to fit the lower frequency data where bubble effects dominate the spectrum. The model fits both velocity and attenuation coefficient data reasonably well in the high frequency domain, indicating a volumetric structural relaxation occurring at a time of 5 nanoseconds, possibly consistent with the response of gliadin-sized molecules to the strain energy input of the ultrasonic pulses (Yeboah et al 1994).

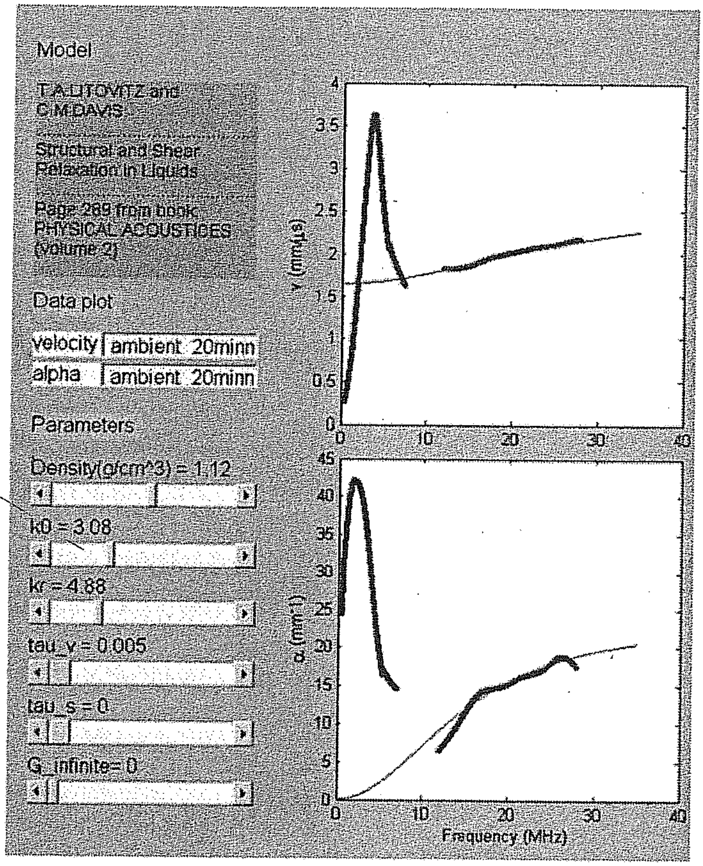

Fig. 4. Fits of a mechanical relaxation model to high frequency velocity (top) and attenuation coefficient (bottom) data

CONCLUSIONS

The mechanical spectrum of dough is dominated by a resonance peak arising from the interaction of ultrasound with bubbles within the dough matrix. The resulting three regions (below, near and above resonance) provide different information on dough properties of interest to cereal scientists, ranging from technologically useful macroscopic properties to insights on molecular events occurring within the dough matrix.

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