Some Observations on Dough Relaxation: The Effect of Bubbles

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ABSTRACT

The rheological complexity of dough leads to a strain-history dependence for its measured rheological properties, so that methods of sampling and testing that add to its strain history potentially alter its measured properties. This study used ultrasound to examine the role of bubbles in dough relaxation following compression. An ultrasonic wavelength was chosen that captures contributions from both bubbles and dough matrix to the overall measured properties of the dough. Doughs were mixed at atmospheric pressure or under vacuum, with the latter process substantially reducing the number of bubbles in the dough. The time-dependent changes in the transit time and amplitude of ultrasonic pulses propagating in dough samples that were subjected to a series of compressive and tensile stresses were recorded. The patterns of change in transit time and amplitude were markedly different in air-mixed doughs to those that had been mixed under vacuum, so bubbles appear to have a substantial effect on the short-time (less than 30 minutes) relaxation behaviour of air-mixed dough samples. These results imply that compressive loading analyses of dough relaxation that focus exclusively on the behaviour of gluten polymers may be incomplete if the effect of bubble deformation and their subsequent relaxation is overlooked.

INTRODUCTION

Examinations of the complex relaxation behaviour of wheat flour doughs have been performed over many decades (Schofield and Scott Blair 1937), with stress relaxation following compression being a tool for investigating dough properties (Launay and Michon 2008). In most relaxation studies of dough, emphasis has focused on understanding how the distribution of relaxation times relates to the nature of the gluten polymers in the dough, e.g., see the review by Dobraszczyk and Morgenstern (2003). Nevertheless, it is important to recognise that compressive stresses not only strain the polymers in the dough, but also the more compressible gas bubbles, and relaxation of these compressed bubbles undoubtedly affects the measured mechanical response (Wang et al 2006). The objective of this study was to use a technique sensitive to the presence of bubbles in dough (low intensity ultrasound) to examine the extent to which the relaxation of compressed dough is affected by its gas bubbles.

MATERIALS AND METHODS

Dough preparation

Lean formula doughs comprised of hard red spring wheat (CWRS) flour prepared by a straight grade milling process on the CIGI pilot mill (100 g), salt (2.4 g) and water (61 mL, for optimal dough handling) were prepared using short-time mechanical dough development in a high-speed pin mixer. Mixing was performed for 5.5 minutes under atmospheric pressure or under vacuum (0.06 atm). A time of 5.5 minutes was optimal as assessed from torque readings during mixing at atmospheric pressure.

Ultrasonic measurements

A pulsed transmission technique was used to measure the pulse's ultrasonic transit time in the dough (from which the velocity can be derived) and the signal amplitude (from which the attenuation can be derived). Dough subsamples were compressed between two transducers. The central frequency of the transducers was 50 kHz (Panametrics). Each transducer was locked in position in the centre of a large steel plate. Edges of the experimental set-up were sealed to prevent dough desiccation during monitoring of the relaxation process.

Dough subsamples of various initial thicknesses were compressed to precisely measure thicknesses by manipulating micrometers separating the two plates. Subsample mass was varied to adjust strain to equivalent levels for different thicknesses. Ultrasonic signals were measured at intervals following a given deformation.

RESULTS AND DISCUSSION

Time-dependent changes in dough properties are expected due to the length of time since mixing (e.g., due to bubble disproportionation (van Vliet 1999)) and due to the length of time since preparation by compression (e.g., due to relaxation of the sample (Phan-Thien and Safari-Ardi 1998)). We examined the effect of both these times on relaxation behaviour by sub-sampling the dough at different times following mixing and subjecting each sample to a regime of compressions and stretchings.

Doughs mixed under vacuum

Doughs mixed under vacuum have few bubbles entrained and so the properties of the dough matrix will dominate the ultrasonic parameters (Scanlon et al 2008). It can be seen from Fig. 1A that in the vacuum-mixed doughs, it does not matter whether the change is qualitatively similar with amplitude steadily rising. We conclude, therefore, that there is no post-mixing time effect on the relaxation behaviour of the vacuum-mixed samples. The amplitude increase persists for a long time, as evident in Fig. 1B, where it is still on-going some 30 hours after the dough was mixed.

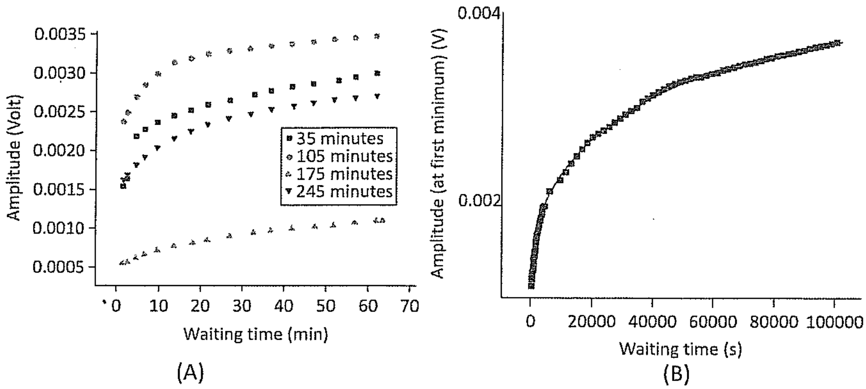

Fig. 1. Change in ultrasonic signal amplitude at a single thickness of 9 mm for samples taken from a vacuum-mixed dough at various times after mixing (A) and for one sample allowed to relax for a long time (B)

When single sub-samples of a vacuum-mixed dough are subject to a series of compressions and stretchings (Fig. 2), the pattern of relaxation is essentially no different to that observed with the multiple samples of Fig. 1. In addition, the pattern of change in ultrasonic signal amplitude is unaffected by the type of stress applied, i.e., the amplitude increases regardless of whether the sample has been compressed or stretched. Similar effects were observed for signal transit time (not shown here).

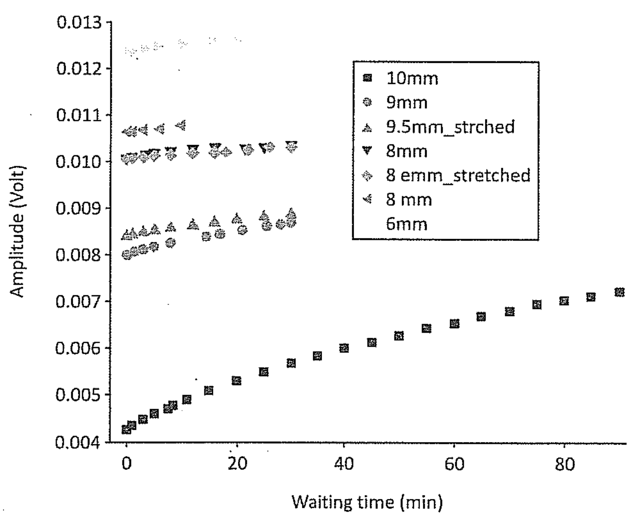

Fig. 2. Change in ultrasonic signal amplitude of a single sample of vacuum-mixed dough with time after being subjected to a series of compressions and stretchings (order in box)

Doughs mixed in air

Doughs mixed in air display a marked difference in their ultrasonic relaxation pattern depending on whether they have been stretched or compressed (Fig. 3), and this effect is manifest in both amplitude and transit time. In contrast to the on-going rise in amplitude in vacuum-mixed doughs, the amplitude falls to attain a finite value in compressed samples. It is only in the samples that have been stretched that amplitude increases. The difference between compression and stretching of air-mixed doughs is readily apparent in the relaxation changes in transit time, with the patterns being mirror images depending on the nature of the applied stress. Regardless of whether the dough has been compressed or stretched, the air-mixed dough displays a short time relaxation that lasts for 20 – 30 min. Polymer relaxation evidently has a bearing on the length of time that a dough specimen must be rested, but these results clearly show that the relaxation of bubbles is also a factor in the dough resting period.

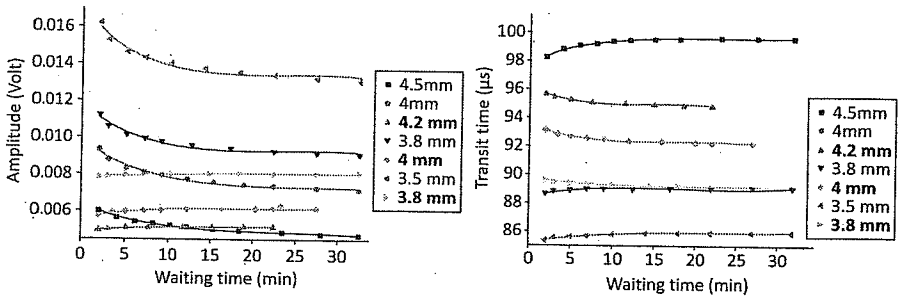

Fig. 3. Change in ultrasonic amplitude (left) and signal transit time (right) of a single sample of air-mixed dough subject to a series of compression (4.5, 4 (1st), 3.8 (1st) and 3.5 mm) and stretching (4.2, 4 (2nd) and 3.8 (2nd) mm) steps (following the order, from top to bottom, in the box)

Bubble relaxation

A putative mechanism can be advanced to explain the difference in pattern of transit time and amplitude relaxation of the two types of doughs. In the vacuum-mixed doughs, there is essentially only dough matrix material, and so the relaxation of polymers in the dough matrix in response to compression dominates the relaxation pattern. Because the dough matrix is highly incompressible (Wang et al 2006), the compressive stresses persist even when the sample has been stretched, e.g., residual stresses from compression to 9 mm endure in the relaxation following stretching to 8.5 mm from 8 mm). Accordingly, the relaxation of the dough matrix dominates and the amplitude increases. In contrast, the air-mixed dough is a "composite" of highly compressible air bubbles and the essentially incompressible matrix. When compressive stresses are applied, the bubbles deform and the applied pressure forces gas into the dough matrix. Over time, the bubbles return to almost their original shape and size. Almost is added since a disproportionation process preferentially drives the dissolved gases from matrix into the larger bubbles (van Vliet 1999). In samples that are stretched, the opposite effect is expected with the time necessary for restoration of the original bubble distribution being approximately the same, as observed. Such a mechanism is tenable if the changes in transit time and amplitude with time are strain dependent, a topic that is addressed in Scanlon et al (2011).

CONCLUSIONS

Differences in the pattern of ultrasonically-measured relaxation in vacuum-mixed and air-mixed doughs indicates that the short-time (30 min) relaxation of dough is strongly affected by the deformation of bubbles in the dough and their subsequent relaxation.

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