

## Large and Fast Deformations Crucial for the Rheology of Proofing Dough

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During proofing, the dough experiences large deformations over a long time. It is generally accepted that for adequate rheological characterization of dough, a large-scale deformation over a long period of time is required. Typical extension rates are between  $10^{-4}$  and  $10^{-3}$ /sec (Bloksma 1990). It is surprising therefore, that mainly the rheological properties at the point of burst in the modified alveograph procedure (at extension rates approaching 1/sec) are well correlated with breadmaking quality (Dobraszczyk and Roberts 1994; Dobraszczyk 1997; Dobraszczyk et al 2002). It is also generally accepted that breadmaking quality is largely determined by the gas cell stability of the proofing dough (Bloksma 1990). Rheological properties like strain-hardening surface tension by surface active components have been associated with this stability (Kokelaar 1994). Various mechanisms have been proposed to explain the gas cell instability such as particles disturbing the gas cell integrity (Gan et al 1990), the presence of surface active components altering the surface tension (Kokelaar 1994), or gelatinization of starch and protein denaturation during baking. Obviously, these changes take place at a microscopic level. Unfortunately, at present, it is still impossible to measure the rheology of dough on a microscopic scale in situ because the current methods are only able to measure the averaged macroscopic rheological properties. This hampers the rheological understanding of the failure of gas cells at a microscopic level.

### Phenomenological Observations of Proofing Doughs

Several phenomenological observations of proofing doughs convinced us that, in a proofing dough, large-scale deformations taking place in a fraction of a second are important for the gas cell stability of dough.

The proofing behavior of doughs was studied by following the volume with a video camera. Doughs were prepared from low quality flour Kolibri (ex. Meneba, The Netherlands) and from flour of the over-strong wheat cultivar Soissons. The doughs contained 2% NaCl, 7% yeast, 100 ppm of ascorbic acid, and 58 or 59% water, respectively (all percentages on flour weight), and were mixed for 9 and 20 min, respectively, in a Do-corder at 20°C. To prolong the proofing time, proofing took place at room temperature. After 50-min proof of the Kolibri dough and 100-min proof of the Soissons dough, sudden decreases in height occurred that could be as large as 25% of the proofed volume (Figs. 1 and 2). Meanwhile, small bulges appeared on the surface that collapsed to form small craters on the surface. After baking, these craters were still visible in the crust. Because no large bulges were observed at the surface that could explain the large and sudden decreases in height observed in Fig. 1, it is speculated that concatenations of gas cells collapsed at once, emptying gas contents through a kind of a chimney to the surrounding atmosphere.

Similarly, doughs were proofed in a normal light microscope (LM, Zeiss Axiovert) (Fig. 3) and in a confocal scanning laser micro-

scope (CSLM, BioRad) fitted with a 15 mW Krypton/Argon mixed gas laser (Fig. 4) with thermostatted object tables (both Linkam THMS 600, Linkam, UK) at 32 and 34–60°C, respectively. With LM, attempts were made to identify whether simple coalescence occurred or if failure of the gas cell membrane between the bubbles was the cause. For this, a dough was prepared from Ibis flour (Meneba, The Netherlands) with 58% water, 5.5% yeast, 200 ppm of ascorbic acid, 40 ppm of amylase, and 100 ppm of xylanase (all contents on flour weight). This dough was proofed for 20 min before placing a small piece of dough on the objective. Despite careful scanning of several samples, the moment of coalescence could not be seen (Fig. 3), indicating that it occurred instantaneously and in less than one timeframe of our video (1/25 sec). Clearly, coalescence was caused by changes outside of the view of the LM, as evidenced by the sudden movements of the surrounding gas cell. It is likely that these movements are caused by collapses of cells outside the view of the LM.

For CSLM, dough from flour of the pure cultivar Soissons was mixed in the farinograph for 7 min at 55 bakers% water, 2% NaCl, and 4% yeast. Dough proteins were stained with rhodamine (0.05%) which, as shown in dough mixing and baking trials, did not affect dough mixing and breadmaking quality. The proteins associated with the starch also clearly discriminated the starch granules. Samples were imaged with 568 nm (yellow) laser excitation with a  $20 \times 0.32$  n.a. long working distance microscope objective. Filter configurations were: Excitor, 568 nm dichroic filter; Dichroic reflector, 585 nm long pass; Emission filter, 585 nm long pass. A rate of  $\approx 1$  scan/sec was used. A Panasonic AG6730 timelapse video recorder was used.

During proofing under the microscope at 34°C, remarkably fast movements of concatenations of starch kernels, most likely embedded in protein, were observed (Fig. 4). This indicated that despite

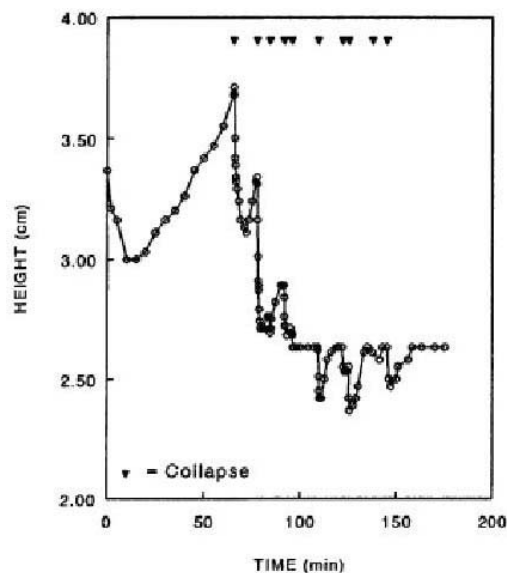


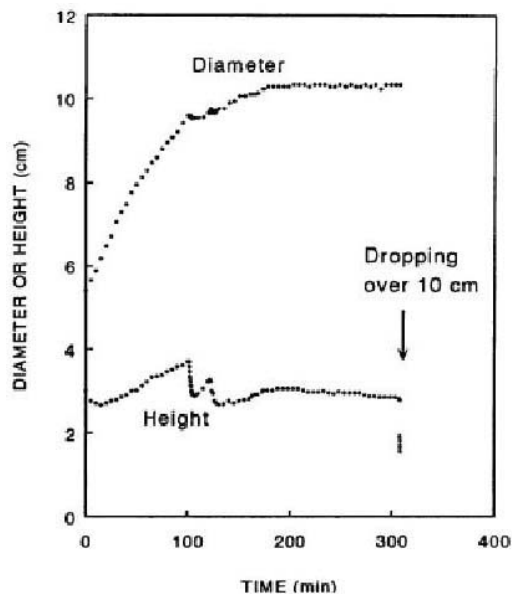
Fig. 1. Expansion in height of Kolibri dough during proofing at room temperature.

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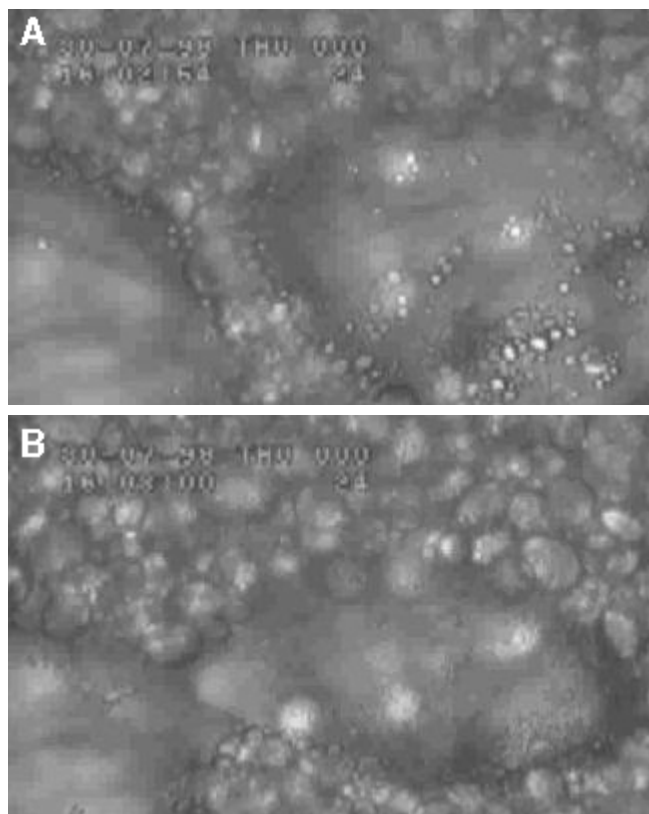
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the slow overall deformation of the dough, internally large and fast deformations took place at the microscopic level. As the temperatures increased from 45 to 55°C, the speed of these movements increased.

Using these observations, a rough estimation of the extension rates during failure can be made on the basis of the measurement of the distances of movement of the largest starch granules ( $\approx 30 \mu\text{m}$ ) and a rough estimation of the time. This resulted in extension rates between  $10^1$  and  $10^2$  sec, or about five orders of magnitude larger than the average extension rate during proofing.



**Fig. 2.** Expansion in height and diameter of Soissons dough during proofing at room temperature.



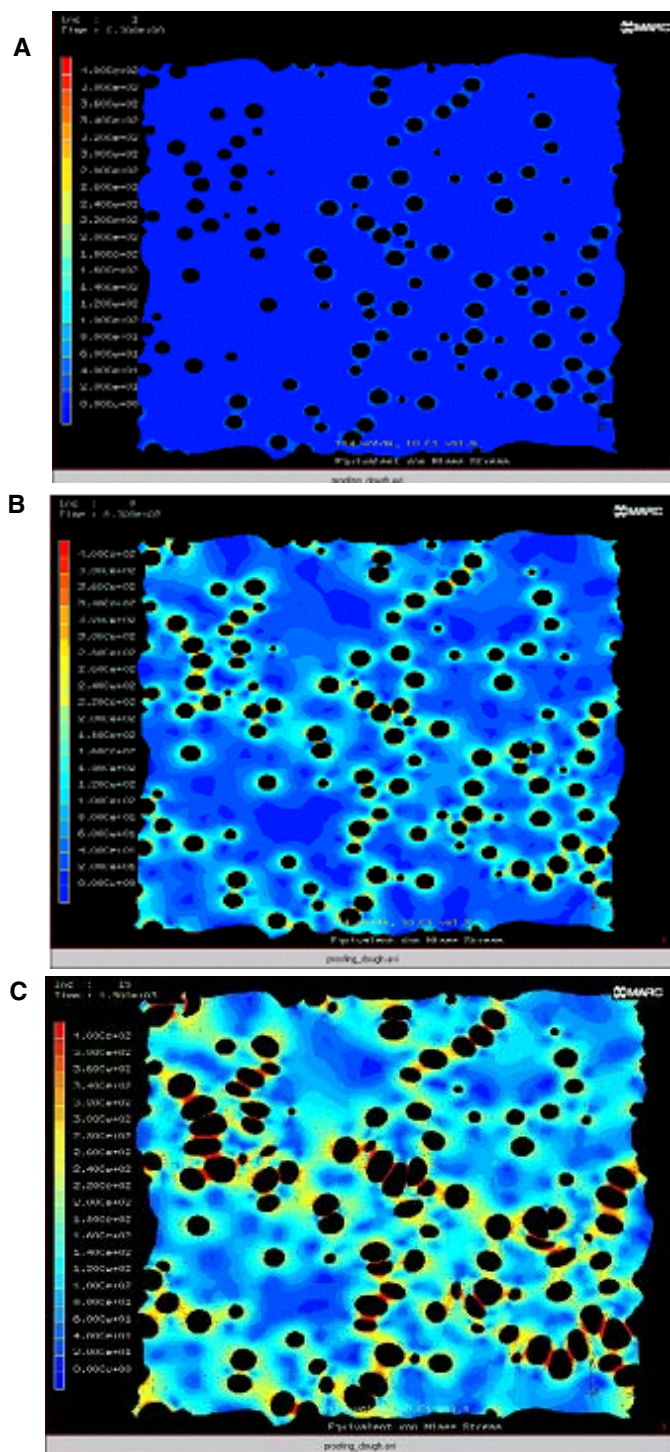
**Fig. 3.** Proofing of an Ibis dough at 32°C in a light microscope before (A) and 1/25 sec after (B) collapse of two gas cells.

Although these phenomenological observations demonstrate that large deformation on a short time-scale can take place, the relationship with and relevance for dough properties is not clear. Rheological modeling of proofing dough gave some surprising insights.

Dough rheology was modeled by combining models of starch rheology and the pom-pom model for gluten similar to the model proposed by McLeish and Larsson (1998) for synthetic polymers. This model fitted the shear behavior of dough at different strain rates relatively well. Prediction of the extensional deformation of dough from shear data was less accurate and needs to be optimized further. Nevertheless, for the first time, this model is able to make a first-order prediction of the dough behavior in uniaxial extension



**Fig. 4.** Proofing of a rhodamine-stained Soissons dough at 34°C in a confocal laser scanning microscope (A), plus 3 sec (B) and plus 7 sec (C). Protein strands are light colored. Arrows indicate starch embedded in protein, moving at relatively high speed.



**Fig. 5.** Simulation of stresses in a proofing dough starting with 10 vol% randomly distributed gas bubbles (A), expanding through 5% (B) up to a total volume increase of 10 % (C) using an integrated rheological model capable of describing both shear and extensional behavior of dough. Red indicates largest stresses, blue lowest. For details on the microscopic modeling see Smit et al (1999).

and shear as a function of strain rate (R. Smit et al, unpublished). This rheological model was used to predict the stresses at a microscopic scale of a proofing dough (expanding 10% in volume)

containing 10% volume fraction of inert gas (for approach see Smit [1999]) (Fig. 5). Although it was not surprising that during the proof the stress in the gas cell membranes between cells increased the most, as described by bulk rheological observations (Dobraszczyk and Roberts 1994; Kokelaar 1994), it was striking that this phenomenon resulted in concatenations of the gas cells. Intuitively, this is a logical consequence of the strain-hardening behavior of the dough: deformations will preferentially take place where the stresses are highest, thus favoring gas cell concatenation. Without our modeling, this logical consequence would have been less evident because discussions on strain hardening, up to now, have only been focused on the cell membrane between two gas cells only. Because we modeled only a 10% volume increase, we do not have the result of the situation at the final stage of proving. However, on the basis of the strain-hardening theory, it can be assumed that the stresses within the concatenations remain the highest, even after all gas cells are surrounded by others at the end of proving. As a consequence of these concatenations, a collapse or burst of a gas cell at the outer side of the dough causes a subsequent collapse of all the connected cells due to a failure of the cell membranes that have the highest stress.

## CONCLUSIONS

In contrast to the generally accepted theories that during proofing extension rates of  $10^{-4}$  and  $10^{-3}$ /sec are important for dough rheology, our observations give clear evidence that, on a microscopic level, extension rates in the order of  $10^1$  and  $10^2$ /sec, (about five orders of magnitude larger) are crucial for the rheological properties. Phenomenological observations of dough collapsing during proofing in combination with the modeling of the stresses in dough suggest that concatenations of gas cells develop during proofing. A collapse of only one gas cell may result locally in a large extension rate that will cause a further destabilization of these concatenations by causing failures of the highly stressed membranes between the gas cells. These changes determine the gas cell stability of the dough during proofing and oven rise and, in turn, the final breadmaking quality.

## LITERATURE CITED

- Bloksma, A. H. 1990. Rheology of the breadmaking process. *Cereal Foods World* 35:228-236.
- Dobraszczyk, B. J. 1997. Development of a new dough inflation system to evaluate doughs. *Cereal Foods World* 42:516-519.
- Dobraszczyk, B. J., and Roberts, C. A. 1994. Strain hardening and dough gas cell-wall failure in biaxial extension. *J. Cereal Sci.* 20:265-274.
- Dobraszczyk, B. J., Smewing, J., Albertini, M., Maesmans, G., and Schofield, J. D. 2002. Extensional rheology and stability of gas cell walls in bread doughs at elevated temperatures in relation to breadmaking performance. *Cereal Chem.* 80:218-224.
- Gan, Z., Angold, R. E., Williams, M. R., Ellis, P. R., Vaughan, J. G., and Galliard, T. 1990. The microstructure and gas retention of bread dough. *J. Cereal Sci.* 12:15-24.
- Kokelaar, J. J. 1994. Physics of breadmaking. PhD thesis. Wageningen: The Netherlands.
- McLeish, T. C. B., and Larson, R. G. 1998. Molecular constitutive evaluation for a class of branched polymers: The pom-pom polymer. *J. Rheol.* 42:81-110.
- Smit, R. J. M., Brekelmans, W. A. M., and Meijer, H. E. H. 1999. Prediction of the large-strain mechanical response of heterogeneous polymer systems: Local and global deformation behaviour of a representative volume element of voided polycarbonate. *J. Mech. Phys. Solids* 47:201-221.

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