The Wheat Research Institute Chomper, an Instrument that Measures Crumb Flexibility

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ABSTRACT

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A bread-shearing machine, the Wheat Research Institute Chomper, records a unique dynamic stress-strain curve, the chompergram. The initial slope of the chompergram enables the determination of crumb flexibility of bread, which is correlated to firmness. Peak height of the chompergram measures the failure of the crumb in tension. This paper covers the theory of the Chomper and the procedure for measuring the above two parameters. A novel method of determining Poisson's ratio is also advanced.

Measurement of the rheological properties of bread crumb is closely related to evaluation of staling, evaluation of dough conditioners, and to general crumb quality control. Several articles that review bread staling or crumb rheology (Platt 1930, Cathcart 1940, Bice and Geddes 1949, Willhoft 1973, Maga 1975, Kulp and Ponte 1981, Ponte and Faubion 1985) devote sections to measurements of firmness, softness, compressibility, and elasticity. Most of these articles refer to papers that describe static compression or extension measurements, although Platt and Powers (1940) first noted that dynamic stress-strain curves were available from concurrent Baker compressimeter readings. Also, Babb (1965) developed a recording instrument that measures both compressibility and shear, Dahle and Montgomery (1978) dynamically measured crumb in shear, and Hibberd and Parker (1985) described several dynamic measurements that were correlated to static firmness measurements.

The Wheat Research Institute Chomper described in this paper balances dynamic compression force against dynamic shear force to determine the initial slope of stress-strain curves and measures the dynamic crumb failure stress under controlled conditions.

The first measurement was suggested by Platt and Powers (1940), Bice and Geddes (1949), Crossland and Favor (1950), and Hibberd and Parker (1985). The measured quantity is called "chompergram slope" or "flexibility" to distinguish it from two closely correlated static measurements called "softness" and "firmness" already defined by Bice and Geddes (1949).

The second quantity is similar to Dahle's and Montgomery's (1978) "strength" measurement. The measurement is called "peak height" in this paper.

Thirdly, a novel method of determining Poisson's ratio is introduced.

The aim of this paper is to describe the theory behind the Chomper and its operation in measuring the above three quantities.

DESCRIPTION OF CHOMPER

Physical Description

Figure 1 is a diagram of the bread-shearing machine named the Chomper that has been designed and developed at the Wheat Research Institute and built by Southern Industrial Development Division, DSIR, Christchurch, New Zealand.

When operated at mains frequency of 50 Hz, an asynchronous, three-phase motor propels the slice platform at a constant lineal rate of 1.1 mm/sec. The addition of an IEA variable speed controller between the motor and mains allows platform speed to be varied proportionally to the applied frequency.

The slice platform moves along a 19.3 mm diameter plunger supported inside the platform by a Rotalin linear bearing. The horizontal plunger enters and exits a vertical slot in the slice platform through holes on either side of the slot. At the anchor end of the plunger is a 230 × 11.3 × 4.4 mm mild steel bar. A Wheatstone bridge configuration of four 120 Kyowa KFC-5-c1-11 strain gauges is mounted, two gauges on each 11.3-mm wide surface. The gauges are 80 mm from each end of the bar. Knife edge clamping supports at both ends connect the bar to the shearing machine frame. The clamps make contact with the bar, but they grip with only a minimum force when the bar is in a neutral position. A Reid K.2 power supply operates the strain gauge bridge through a precision 4 ± 0.01 V voltage regulator. The response of the bridge to a force on the plunger is 0.029 mV/N and is linear in the range of use (zero N to roughly 15 N). A Linseis L-800 X-Y recorder records the strain gauge bridge signals on a choice of 15 ranges from 0.1 mV/cm minimum to 5 V/cm maximum after preamplification of either 100 or 200 in an N 31 Linseis preamplifier. The plunger face is ground square to the cylindrical sides, with no bevelled or blunted edges. The slot hole in the Perspex slice platform is also square faced. The plunger and the hole are the same diameter, the one fitting into the other in a sliding fit.

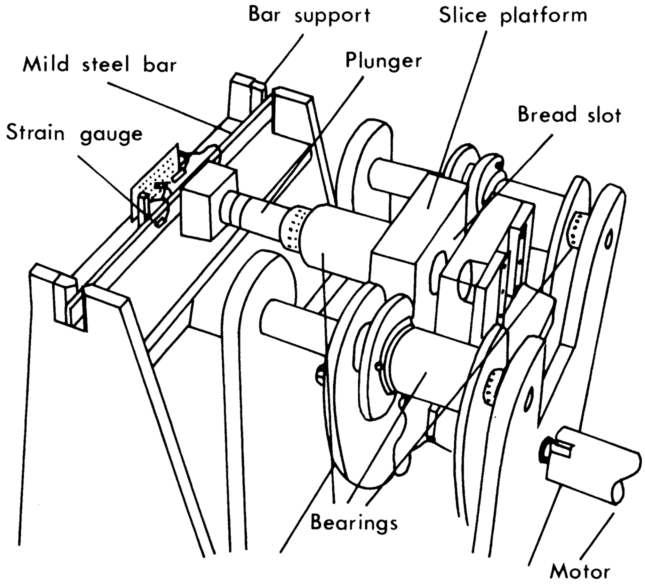

Fig. 1. The Chomper. A constant speed motor drives a moving platform containing a sample slice along a fixed plunger. A Wheatstone bridge configuration of strain gauges mounted on a mild steel beam at one end of the plunger monitors the stress transmitted to the plunger from the slice. The platform moves on three linear bearings over two guides at its sides and the plunger at its center.

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Operating Theory

The strain gauge response is due to the balance between the compressive force that the plunger exerts on the crumb and the reactive shear force of the crumb in the platform slot.

Figure 2 is a diagram of bread crumb deformation in the slice platform slot as the platform moves on to the plunger. The dashed lines outline the shearing strain in the crumb.

For the purposes of the following derivations it is assumed that during successive small time intervals at the beginning of deformation, the deformation should behave approximately elastically within each time interval, though not necessarily between time intervals. In terms of the dimensions of Figure 2E, the well-known elastic relations (Sommerfeld 1964) for stress forces due to compression and shear are:

for compression

$$F_c = \left[\frac{E}{(1+\nu)}\right]\left[\frac{(x-w)}{W}\right]\left[\frac{(1-\nu)}{(1-2\nu)}\right]\left[\frac{\pi D^2}{4}\right] \qquad (1)$$

and for shear

$$F_s = \frac{E\, w\, \pi\, [W-(x-w)]}{(1+\nu)} \qquad (2)$$

where D is the diameter of the plunger, x is the distance the platform has travelled, W is the slot width (and therefore slice thickness), w is the length of crumb deformation horizontally into the hole opposite the plunger, E is Young's modulus, and ν is Poisson's ratio.

The average compressive stress is given by

$$\sigma_s = \frac{4F_c}{\pi D^2} \qquad (3)$$

and the average shearing stress is given by

$$\sigma_s = \frac{F_s}{\pi D[W-(x-w)]} \qquad (4)$$

Experimentally the additional empirical relationship

$$w = kx \qquad (5)$$

can be demonstrated where k is a proportionality constant. Since $W = 12.5$ mm and $D = 19.3$ mm, the value of Poisson's ratio at any deformation x is available from following the formula, derived by equating compressive and shear forces

$$\nu = \frac{(997.5 - 50x + 50kx)k - 372.5}{(1622.5 - 100x + 100kx)k - 372.5} \qquad (6)$$

If the model is approximately correct, the physical values for Poisson's ratio should be between zero and 0.5 (Westergaard 1964), although the mathematical limits are -1 to 0.5 (Jaeger 1962).

Since Poisson's ratio is determined at any value of x, and the value of the stress due to the plunger is available at that value, the value of Young's modulus, the modulus of elasticity, can also be determined from the equation

$$E_x = \frac{(1-k)\,(1-\nu_x)\sigma_x x}{W(1+\nu_x)\,(1-2\nu_x)} \qquad (7)$$

where the subscript x indicates a numerical evaluation of E, σ, and ν at chosen values of x.

If the values of the following expression

$$\frac{(1-k)\,(1-\nu_x)\,x}{W(1+\nu_x)\,(1-2\nu_x)} \qquad (8)$$

for different values of k are plotted against x, this function is found to rise nearly linearly, although the derivative of Poisson's ratio with respect to x is negative, and the coefficient of x in equation 8 expression decreases with increasing x. Hence, the greater the derivative of the stress with respect to x, the faster the elastic modulus, E, increases and the more firm the crumb feels.

Young's Modulus

The coefficient of the stress component σ_x in the Young's

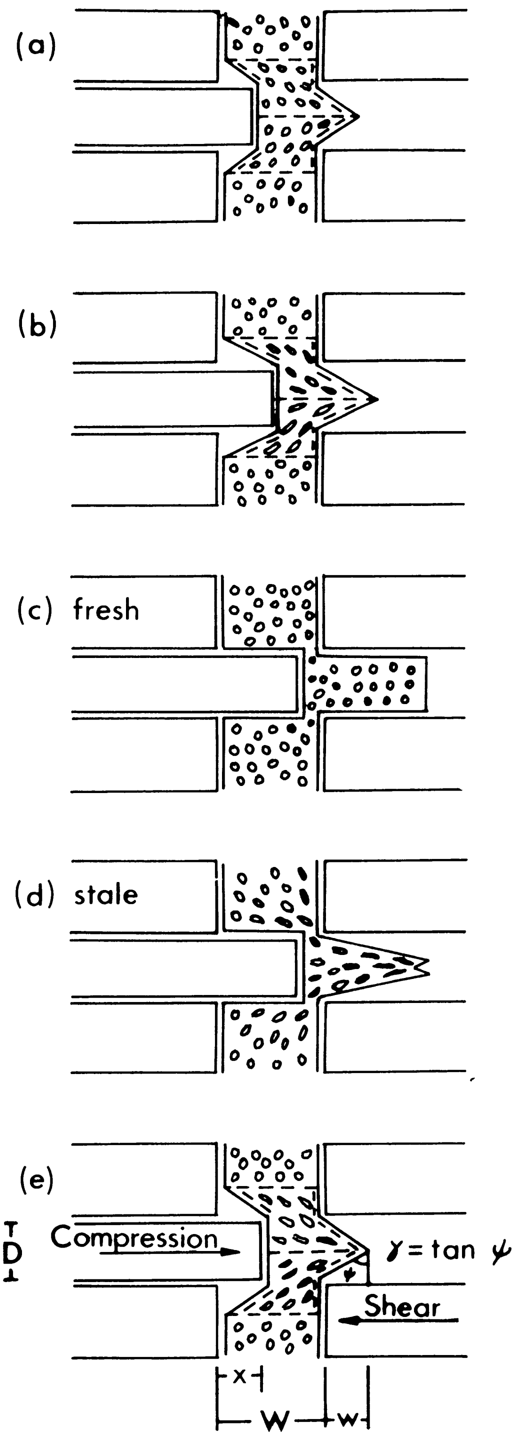

Fig. 2. a, At the beginning of the indentation the shear angle is so small that the strain could be mistaken for pure compression. **b,** As the indentation increases, the strain causes elongation of the crumb cells. **c,** Fresh crumb ruptures concurrently at the leading plunger hole edge and the edge of the plunger and works toward the center. **d,** Stale crumb ruptures concurrently at the tip of the cone and the edge of the plunger. **e,** Stress diagram: **x** is the plunger indentation, **W** is the sample width, **D** is the plunger diameter, ψ is the shearing angle, and **w** is the extension of the crumb cone beyond the slot face.

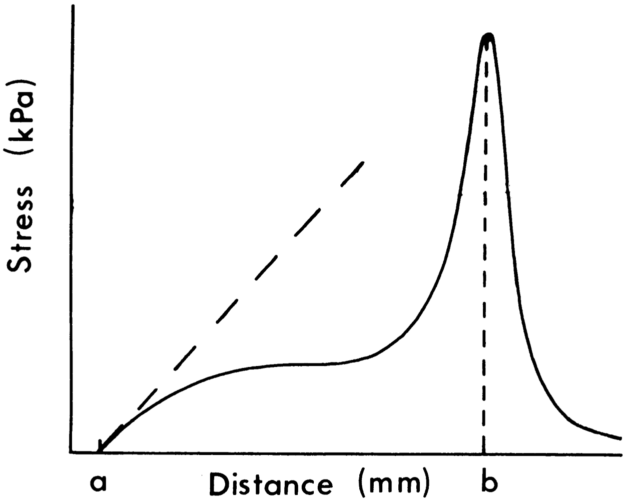

Fig. 3. The chompergram. The initial slope of the stress distance curve is measured at **a** in kPa/mm. The peak height is measured in kPa at the failure point, **b**.

modulus in equation 7 can be calculated at specific platform displacements when k from equation 4 is known. The resulting value increases linearly at the rate of approximately 0.04 mm^{-1} within the range $k = 0.54$ to $k = 0.62$. Because the stress component also increases with advancing platform displacement, the product, Young's modulus, will also increase with platform displacement. The chompergram slope is thus an indication of the rate of change in Young's modulus at very small platform displacements.

Visual Observation

There appeared to be two forms of bread crumb rupture. When the rupture occurred concurrently on both leading and trailing crumb surfaces at the perimeter of the slot hole and plunger, the rupturing began at the two surfaces and worked to the center. This type of failure seemed to occur most readily in fresh slices (Fig. 2C).

Slices older than 30 hr usually ruptured concurrently at the tip of the cone on the leading surface and at the perimeter of the plunger on the trailing surface. The trailing surface rupture then worked its way forward to the leading surface (Fig. 2D).

TEST PROCEDURES

Graph Measurements

To produce a typical chompergram (Fig. 3), the platform is first positioned so that the plunger is completely clear of the bread slot. The platform and recorder pen are set in motion, the latter usually at 20 mm/sec for a motor speed corresponding to 50 Hz. The motion of the platform is halted after the plunger has punched clear a plug of crumb into the hole on the far side of the slot. The vertical scale records the stress exerted on the bread by the plunger. The horizontal scale is proportional to the linear displacement of the platform (x in Fig. 2E).

The two measurements made from the chompergram are the slope at position "a" (as close to the origin as possible) and the peak height at "b." The slope at "a" is estimated by Hartree's (1958) geometric method:

> The best way of finding the gradient ... representing a set of results of some experiment or observations is as follows. Take a flat piece of polished sheet metal (aluminium or stainless steel is satisfactory), or surface-aluminized glass, mounted in such a way that it can be placed on a piece of paper with its surface accurately perpendicular to the paper and extending right down the paper. Set this so as to intersect the curve at the point at which the gradient is wanted, and rotate it until there is no discontinuity in direction between the curve and its reflection in the mirror. With care, this setting can be made with considerable accuracy, probably greater than that to which the curve can be drawn. The gradient of the curve can then be determined directly from the intersections of the plane of the mirror with the grid lines of the paper in which the curve is plotted.

Poisson's Ratio

To measure (x-w) (Fig. 2E) for Poisson's ratio computation (eq. 6), the platform is advanced onto the plunger by hand. The distance from the end of the platform to the tip of the crumb cone is measured with a depth gauging vernier at each half revolution of the drive screw.

Cutting Sample Slices

To ensure a uniform thickness of slice in an experiment, a 254-mm diameter A 37 h hollow ground miter bench saw turning at 44 lineal m/sec can be used to cut the loaves to a thickness of 13 mm. The slices should be taken from the centers of halved loaves and should comprise the bottom 75 mm of the loaf. This is to ensure that external effects (such as greater water migration from the end of the loaf or effect of pan type on crumb structure) are minimized. Each slice is trimmed of its crust. A Mono reciprocating slicer may also be used to provide 12.5-mm slices.

CONCLUSION

The Chomper is a bread-shearing machine that provides dynamic measurements of crumb flexibility and crumb failure under tension. These measurements are used to assess the effects of staling of bread in a companion paper (Baruch and Atkins 1989).

The advantage of dynamic over static measurements is that the situation where bread is handled or eaten is better simulated by a dynamic action.

The Chomper also provides a novel means of measuring Poisson's ratio for bread crumb.

LITERATURE CITED

BABB, A. T. S. 1965. A recording instrument for the rapid evaluation of the compressibility of bakery goods. J. Sci. Food Agric. 16:670.

BARUCH, D. W., and ATKINS, T. D. 1989. Using the Wheat Research Institute Chomper to assess crumb flexibility of staling bread. Cereal Chem. 66:00.

BICE, C. W., and GEDDES, W. F. 1949. Studies on bread staling IV. Evaluation of methods for the measurement of changes which occur during bread staling. Cereal Chem. 26:440.

CATHCART, W. H. 1940. Review of progress in research on bread staling. Cereal Chem. 17:100.

CROSSLAND, L. B., and FAVOR, H. H. 1950. A study of the effects of various techniques on the measurement of the firmness of bread by the Baker Compressimeter. Cereal Chem. 27:15.

DAHLE, L. K., and MONTGOMERY, E. P. 1978. A method for measuring strength and extensibility of bread crumb. Cereal Chem. 55:197.

HARTREE, D. R. 1958. Page 129 in: Numerical Analysis, 2nd ed. Oxford at the Clarendon Press: Oxford.

HIBBERD, G. E., and PARKER, N. S. 1985. Measurements of the compression properties of bread crumb. J. Texture Stud. 16:97.

JAEGER, J. C. 1962. Page 57 in: Elasticity, Fracture and Flow. Methuen and Co.: London.

KULP, K., and PONTE, J. G., JR. 1981. Staling of white pan bread: Fundamental causes. CRC Crit. Rev. Food Sci. Nutr. 15:1.

MAGA, J. A. 1975. Bread staling. Crit. Rev. Food Technol. 5:443.

PLATT, W. 1930. Staling of bread. Cereal Chem. 7:1.

PLATT, W., and POWERS, R. 1940. Compressibility of bread crumb. Cereal Chem. 17:601.

PONTE, J. G., JR., and FAUBION, J. M. 1985. Rheology of bread crumb. Page 241 in: Rheology of wheat products. H. Faridi, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

SOMMERFELD, A. 1964. Page 65 in: Mechanics of deformable bodies. Lectures on Theoretical Physics. Vol. 2. Academic Press: New York.

WESTERGAARD, H. M. 1964. Page 80 in: Theory of Elasticity and Plasticity. Dover Publications: New York.

WILLHOFT, E. M. A. 1973. Mechanism and theory of staling of bread and baked goods, and associated changes in textural properties. J. Texture Stud. 4:292.

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