Grain Research Laboratory Compression Tester: Its Description and Application to Measurement of Bread-Crumb Properties

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ABSTRACT

The Grain Research Laboratory compression tester, a versatile instrument for the measurement of the textural properties of bread crumb, is described. A plunger attached to a force transducer is moved vertically by a variable-speed motor-driven cam that provides precise, repetitive compression of foods either to constant deformation or to constant force in conjunction with a comparator. To demonstrate the potential of the instrument, textural properties including firmness, stress relaxation, cohesiveness, and stickiness were measured in bread crumbs from loaves stored for various periods of time.

To the consumer, freshness is a primary factor in the assessment of bread quality. Bread that has a soft yet somewhat springy feel as determined by the "squeeze-test" is usually considered highly desirable. This perception of freshness is largely a reflection of the textural properties of the crumb. Therefore, several studies have been performed to determine crumb properties, with the major emphasis being placed on the effects of aging (staling). Two basic experimental approaches have dominated in these studies.

In the first approach, bread slices are subjected to a constant deformation, and changes in force are recorded. The most commonly measured textural characteristic is the maximum force or firmness. The instrument best known for this measurement is the Baker Compressimeter, which is the basis of the standard AACC bread compression test for staleness (AACC 1980). Using this instrument, Crossland and Favor (1950) showed a linear relationship between firmness and bread age. Although the Baker Compressimeter is widely used in the baking industry, the instrument is not amenable to the measurement of other textural characteristics. These characteristics, including those defined by Szczesniak (1963) on the basis of test panel results, include textural characteristics such as cohesiveness, elasticity, adhesiveness, stickiness, and stress relaxation, in addition to firmness. These characteristics can be measured from force-time curves produced by instruments such as the General Foods Texturemeter (Friedman et al 1963), in which foods are repeatedly subjected to constant deformation. However, this machine has the disadvantage that theoretical analysis of the results in terms of basic rheological equations is difficult because of the sinusoidal deformation motion of the articulator lever. These problems can be overcome by using instruments such as an Instron (Hindman and Burr 1949), in which constant and reproducible deformation rates are maintained. Using the Instron, Bashford and Hortung (1976) correlated parameters derived from standard rheological terms with test panel evaluation of bread freshness. Rheological terms found to be closely related to bread freshness included load (firmness) of the first loading cycle at constant deformation, the ratio of load to deformation, and the elastic modules, determined from stress-relaxation curves.

The second approach for evaluation of bread aging involves compression of bread slices with a constant force and measurement of the changes in deformation. A number of studies have used penetrometers of fairly simple design to study bread staling. Bradley and Thompson (1950) and Bechtel et al (1953) compressed bread slices with a force of 215 g for 10 sec, using a penetrometer equipped with a 3-mm-diameter disk. Their results demonstrated a decrease in compressibility with bread age. Later studies by Cornford et al (1964) and Axford et al (1968), using a cone penetrometer, showed a similar relationship between crumb elastic modules and staling in bread. Crumb modulus plotted against time gave a curve in general agreement with the Avrami theory for predicting starch crystallization. Similar results were obtained by Kim and D'Appolonia (1977) when they used an Instron. McDermott (1974) described a simple instrument for measuring stickiness, compressibility, and resilience of fresh bread. Bread-crumb stickiness decreased, and resilience increased rapidly over a 3-hr period after removal from the oven. A simple cone penetrometer was also described by Lasztity (1980) for measuring bread-crumb compressibility, plastic deformation, elastic deformation, and relative elasticity.

Compared to the Instron, all of the above instruments are of fairly simple design and are relatively inexpensive and easy to use. However, unlike the Instron, these instruments are restricted to a narrow range of measurements. Furthermore, the Instron and other linear universal testing machines (Voisey 1971) are advantageous in that compression rates are linear and, thus, force-time relationships can be directly converted to force-compression curves.

We designed a bread-crumb texture measuring device that is

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relatively inexpensive to build and easy to use. It has many of the advantages of linear universal testing machines, including linear force-deformation relationships and the ability to perform constant-compression or constant-force measurements. The instrument, the Grain Research Laboratory (GRL) compression tester, is described, and its application to the measurement of bread crumb texture properties under conditions of constant compression is illustrated.

MATERIALS AND METHODS

GRL Compression Tester

The principle parts of the GRL compression tester are shown schematically in Fig. 1. Peripheral equipment is shown in Fig. 2. The support frame includes a base plate (350 × 300 × 12 mm), a vertical front plate (275 × 140 × 10 mm), and two triangular vertical side plates with heights of 275 mm, thickness of 10 mm, and base width of 125 mm.

For the program cam-drive system, dual sets of ball bearings are mounted in a steel tube passing through and anchored to the front plate of the vertical support at a center shaft height of 250 mm above the base plate. A 12.7-mm diameter camshaft is mounted on the ball bearings and attached at one end to the program cam. The shaft is driven from a variable speed (0.13–5 rpm) Bodine shunt wound control gear motor (no. 536) via a no. 25 chain, a 16-tooth sprocket attached to the motor, and a Dalton 32T sprocket safety clutch attached to the camshaft. This allows variable camshaft speeds of 0.09–2.69 rpm by use of an appropriate motor speed controller. The safety clutch is preset to slip at 0.9 kg-m to protect the motor gear train from damage if travel of the cam on other driven parts becomes blocked.

Program cams, which drive the plunger assembly, were made from 6.3-mm aluminum plates, using a relatively simple machining procedure involving two holes and two turnings on a lathe. Details of the program cam used in the present study and its projected performance are shown in Fig. 3. The center hole was used for machining the larger circular portion of the cam, and the lower hole was first used to machine the part of the cam that was at a constant radius with respect to the camshaft. The projected vertical movement of the block and adjustable plunger for one complete rotation of the cam was linear for 32 mm of travel both before and after the dwell (constant-radius) period. This linear-dwell-linear period constitutes the maximum useful range of testing with this particular cam and represents 191° of cam travel and a plunger travel of 32 mm. The remaining 169° moves the plunger an additional 12 mm, which provides for ample clearance for inserting or removing test samples. The nonlinear movement of the plunger for this portion of travel is of no consequence. The rate of travel of the plunger during the linear phase is directly proportional to the cam speed. Therefore, the practical range for testing with this particular cam is from 0.3 to 8.75 mm/sec (.09–2.69 rpm). The

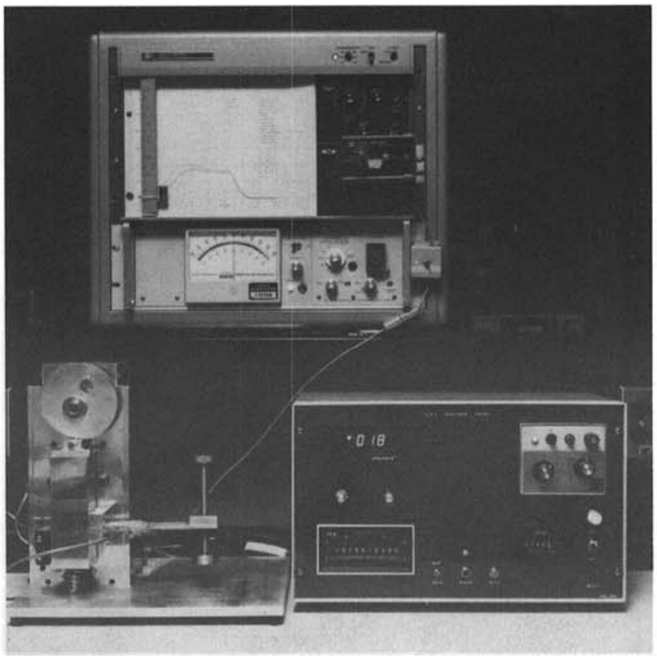

Fig. 2. **Top,** cabinet containing X-Y recorder and strain-gauge amplifier. **Bottom left,** Grain Research Laboratory compression tester. **Bottom right,** cabinet containing meter, comparator, motor speed controller, and associated electronics.

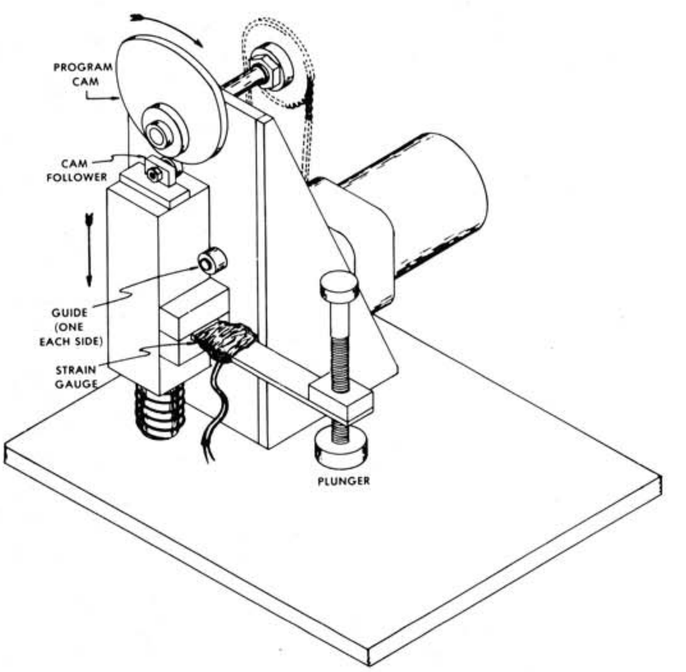

Fig. 1. Principle parts of the Grain Research Laboratory compression tester.

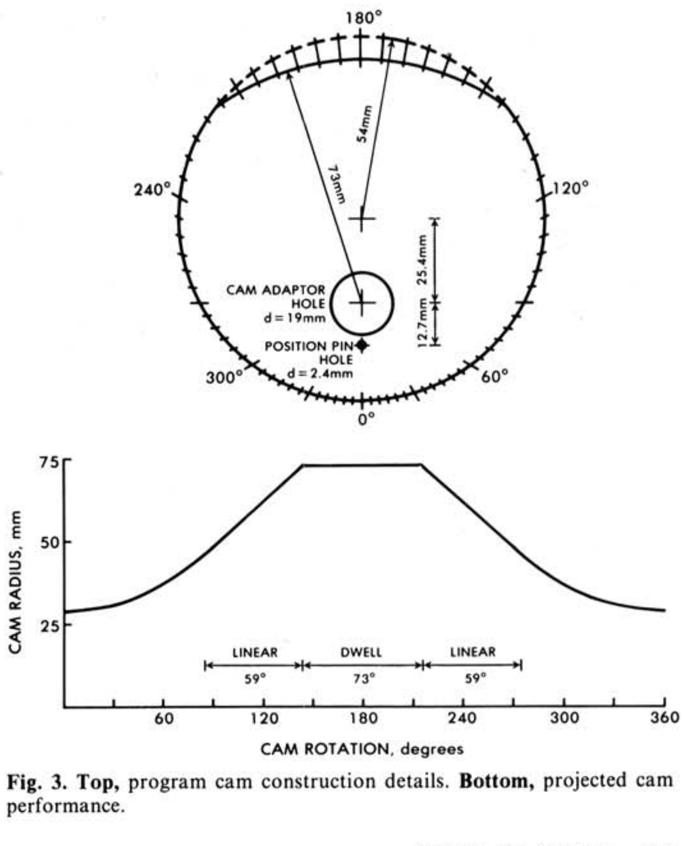

Fig. 3. **Top,** program cam construction details. **Bottom,** projected cam performance.

dwell period is also dependent upon the cam speed. However, when required, the dwell period can be extended by either manually stopping the motor for the required time or by using an adjustable timer controlled by a trip switch attached to the cam in the dwell position.

The lower hole was next machined to fit the cam to the camshaft adapter. This adapter (of brass) permits a quick change of cams while a close-fitting positioning pin prevents slipping and backlash.

The program cam is kept in firm contact with a cam follower attached to a moveable block of aluminum 50 mm square and 152 mm high that can move vertically on a 25-mm-diameter brass post anchored to the base plate. Rotary motion of the block is prevented by guides (cam followers) attached to the vertical face plate and bearing against the sides of the block. The block cam follower is maintained against the cam by a "return" spring located between the base and the block.

A force transducer employing strain gauges extends out from the block approximately 170 mm and provides for a threaded shaft that allows for both plunger height adjustment and use of different plungers. The plunger (Fig. 4) was made from stainless steel and had a diameter of 35.7 mm (area of plunger surface = 1,000 mm^2). A nylon set screw was used to lock the plunger shaft in position.

The peripheral equipment (Fig. 2) consists of a Daytronic amplifier 300D type 93, a Hewlett-Packard X-Y recorder model 7035B, and a cabinet (440 × 270 × 230 mm) containing an analogic digital panel meter, a BCD tracking Comparator series 2500 (Industrial Timer Corp.), an elapsed time meter, a Bodine motor-speed controller 901, and function-switching circuitry. A modified, adjustable Hewlett-Packard time base was used to provide a horizontal pen movement rate of 12.7 mm (0.5 in.)/sec. The time base is started and later reset from a micro switch that is activated by the vertical position of the aluminum block, ie, the descending block position switches time base to sweep, which starts the horizontal movement of the pen; the rising block passing through the same micro switch trips the position to "reset," which drives the pen back to the zero position. This function may be switched off, thereby restoring the time base to its original manual three-position switch of reset, hold, and sweep.

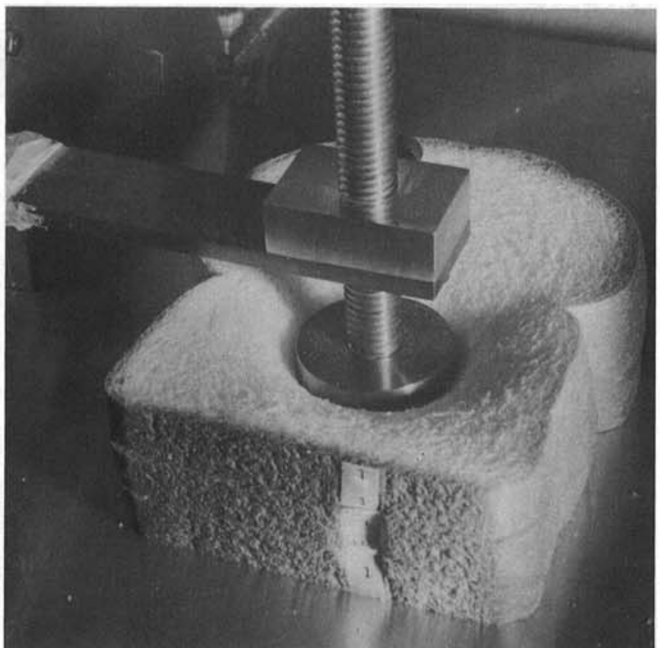

Fig. 4. Plunger in contact with bread crumb at point of 50% compression.

Calibration

For constant-deformation studies, the plunger (Fig. 4) was adjusted to the desired height, using machined steel-gauge blocks of various thicknesses that were placed in conjunction with feeler gauges under the plunger. A change in thickness of as little as 0.01 mm produced visible movement of the recorder pen.

After we established that the force transducer responded similarly to either upward or downward forces, force calibrations were performed by placing appropriate weights on top of the knob of the plunger-adjusting screw. This requires zeroing the recorder with the weight in position, then removing the weight and observing the change in pen deflection. After calibration through strain-gauge amplifier adjustments, the pen was zeroed in the normal way.

For compression to a constant force (not used in the present study), the analog signal from the strain gauge is digitized by the analogic panel meter and its output applied to the comparator. The maximum force desired is then in digital form on the comparator. When compression force reaches the selected maximum force, the comparator turns off the motor. The reverse cycle is initiated manually by reversing the motor after the desired dwell period. An electronic brake coupled to the motor and comparator is used to minimize overshoot. Provisions were also made for automatic reversing when very short dwell periods are used.

Preparation and Measurement of Bread-Crumb Properties

The straight grade flour was obtained by milling a sample of No. 1 Canada Western red spring wheat of 13.5% protein (No. 1 CWRS-13.5) in the GRL Pilot Mill (Black et al 1981). Chemical and physical properties of the flour were very similar to those of the sample used in previous studies (Black et al 1982, Preston et al 1981). Protein content was 12.8%, farinograph absorption was 65.3%, farinograph dough development time was 5.50 min, and extensigraph area was 130 cm^2. A commercial straight grade flour of 8.7% protein, milled from a sample of Canada Eastern white winter (CEWW) soft wheat, was used to prepare blends with the No. 1 CWRS flour.

Bread from the No. 1 CWRS flour and blends of the No. 1 CWRS and CEWW flour were processed by the GRL Chorleywood procedure (Kilborn and Tipples 1981), using the GRL 1000 Mixer (Kilborn and Tipples 1974) and scaling for 1-lb loaves. Following baking, the bread was allowed to cool for 1 hr, wrapped in cellophane bags, and stored for various periods of time. Before

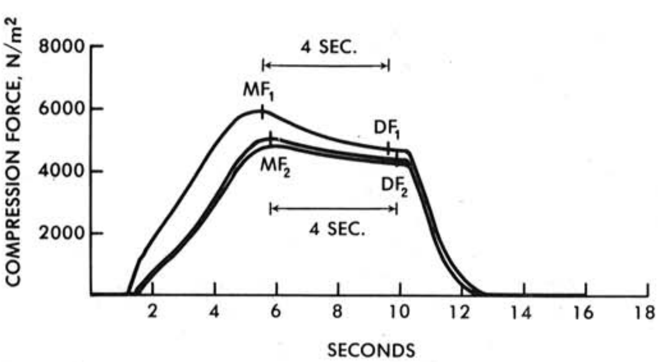

Fig. 5. Compression curves obtained from three rotations of cam.

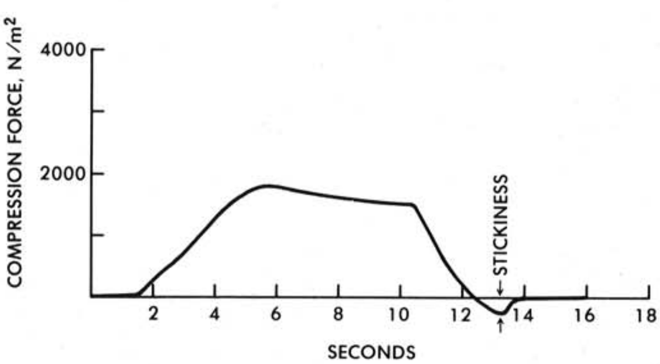

Fig. 6. Compression curves showing stickiness of bread crumb.

testing, loaves were sliced with an Oliver model 792G commercial slicer.

For bread-crumb measurements, the program cam shown in Fig. 3 was used with a cam speed of 2 rpm. The linear speed of the plunger was 6.5 mm/sec, and the dwell period before upward plunger movement was 6.0 sec. Three slices of bread obtained from the center portion of each loaf (in triplicate) having a combined thickness of 38 mm were subjected to 50% deformation as shown in Fig. 4. The program cam was allowed to recycle to give a second deformation of the same cycle. Cycling time was 30 sec.

RESULTS

The reproducibility of the entire system for measurements of constant deformation was tested by placing steel shims beneath the gauge block as described in the previous section. The gauge block and shims were set at a height of 19.0 mm, which corresponded to a deformation of 50% when three slices of bread were used. Curves were obtained by cycling the plunger 10 times, with the plunger height adjusted to give a compression force of approximately 400 g on the block. A change in deformation of 0.06 mm caused an average increase in force of 320 g. Using the linear relationship between force and distance, the error in flatness of cam performance was found to be .015 mm maximum or 0.08% of deformation. This includes any variation in radius between the cam adapter center and the machined constant-radius portion (dwell) of the cam and the tracking of the cam itself on the cam follower and the position guides. The 10 repeat cycles for maximum force averaged 412 g with a standard deviation of 2 g, using a full scale sensitivity of 1,000 g. Variations in the start and finish of curves were less than 0.2 sec for the 10 30-sec compression cycles. This demonstrated that only very small errors occurred because of variations in motor speed, the time base micro-switch function, and the recorder servo system. The deflection of the force transducer beam measured at the plunger for a 500-g force was 0.09 mm.

Measurement of Bread-Crumb Texture Properties

As discussed previously, bread-crumb properties were assessed by compressing three slices of bread to 50% deformation (19 mm), holding the deformation constant for 6 sec, and then repeating the cycle. The dwell period was included to allow an estimate of stress relaxation. A typical texture curve is shown in Fig. 5.

Several crumb textural properties were measured. The maximum force or firmness at constant deformation, which is the measurement most widely used in bread staling studies, was measured for all samples. Measurements related to stress relaxation and cohesiveness were also obtained. Stress relaxation was expressed as the ratio of the decrease in force after 4 sec of dwell time (at constant deformation) to the maximum force during the first compression cycle. Cohesiveness was estimated as the ratio of the maximum force of the second cycle to the maximum force of the first. For fresh bread, stickiness was determined by measuring the maximum reverse force after the first cycle (Fig. 6).

Measurements of textural properties were obtained on GRL Chorleywood-processed bread. This procedure was chosen to minimize loaf volume differences between treatments. In the first study, the effect of storage time on textural properties of bread obtained with 100% No. 1 CWRS and a blend of 55% No. 1 CWRS and 45% CEWW wheat flours was determined. In the second study, the effect of malt level and storage time was studied, with particular emphasis on stickiness. For both studies, measurements were made in triplicate. Average coefficients of variability for firmness, stress relaxation, cohesiveness, and stickiness were 4, 2, 4, and 8% respectively.

Changes in crumb textural properties of bread from the No. 1 CWRS and the CWRS-CEWW blend flours during 6.75 days of storage are shown in Table I. Loaf volumes averaged 2,635 and 2,525 cc, respectively. With both flours, firmness increased markedly with bread age. In agreement with previous studies (Crossland and Favor 1950), the rate of increase in crumb firmness was essentially linear with storage time (Fig. 7). Differences according to flour type were also evident in the crumb-firmness values at equivalent storage times. In particular, the bread from 100% CWRS tended to give lower firmness values during the first three days of storage. These differences may be partly due to differences in loaf volume, which were previously shown to affect firmness (Axford et al 1968). Differences in absorption and flour strength may also have contributed.

Values for stress relaxation after 4 sec of dwell time as a percentage of the maximum force (firmness) showed increases with bread age. Bread from 100% CWRS flour gave lower values than loaves baked from the CWRS-CEWW blend at all storage times. Values for cohesiveness decreased during storage, with greater changes occurring with the CWRS-CEWW blend loaves. Both of these texture characteristics may be related to the consumer's conception of bread springiness or resilience, although further studies are required.

Table II shows the effect of malt level upon the textural properties of the GRL Chorleywood bread produced from No. 1 CWRS flour. Malt levels were varied from 0.3 to 2.4% of 60° L barley malt. In addition to firmness, stress relaxation, and cohesiveness, measurements of bread-crumb stickiness were obtained by measuring the maximum reverse force after the first compression cycle. Bread storage times were reduced to 42 hr because stickiness is highest in fresh bread (McDermott 1974).

Loaf volumes increased from an average of 2,770-3,000 cc as malt level was increased from 0.3 to 2.4%. As in the initial studies,

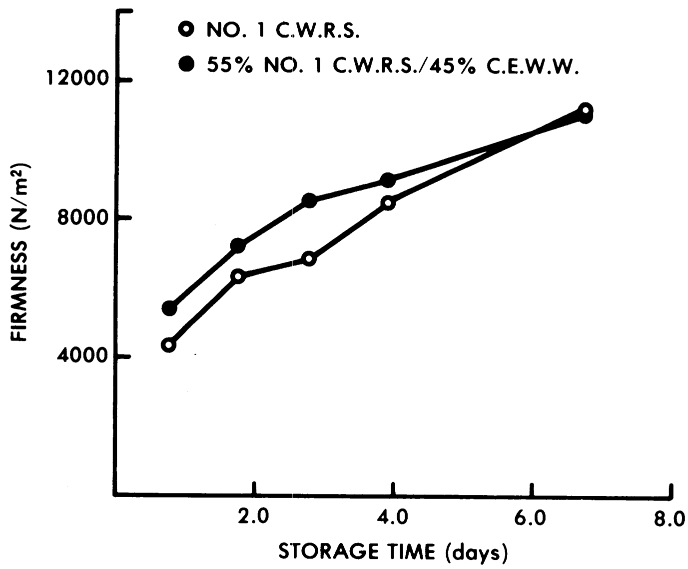

Fig. 7. Effect of bread storage time on crumb firmness.

TABLE I
Effect of Flour Type and Loaf Storage Time on the Textural Properties of GRL Chorleywood-Processed Bread

Flour Blend[a]	Storage Time (days)	Firmness (N/m^2)	Stress Relaxation (%)	Cohesiveness
100% CWRS	0.75	4,360	16.8	0.890
	1.75	6,310	18.5	0.858
	2.75	6,830	20.3	0.854
	3.75	8,480	22.7	0.827
	6.75	11,180	27.0	0.772
55% CWRS/ 45% CEWW	0.75	5,360	19.7	0.866
	1.75	7,190	24.2	0.817
	2.75	8,580	26.8	0.783
	3.75	9,080	27.7	0.769
	6.75	11,030	33.1	0.743

[a]For the 100% CWRS, baking absorption was 65% and loaf volumes averaged 2,630 cc. For the 55/45 CWRS/CEWW blend, baking absorption was 59%, and loaf volumes averaged 2,570 cc.

TABLE II
Effects of Malt Level and Loaf Storage Time on the Textural Properties of GRL Chorleywood-Processed Bread

Malt Level[a] (%)	Storage Time (hr)	Firmness (N/m^2)	Stress Relaxation (%)	Cohesiveness	Stickiness (N/m^2)
0.3	2	1,810	16.2	0.919	245
	18	4,270	17.2	0.897	118
	42	5,790	18.6	0.873	98
0.6	2	1,770	13.9	0.944	235
	18	3,820	17.9	0.897	157
	42	6,080	19.4	0.871	98
1.2	2	1,570	13.8	0.935	255
	18	3,780	19.5	0.883	177
	42	5,835	21.8	0.849	49
2.4	2	1,570	18.8	0.906	274
	18	4,320	20.4	0.864	196
	42	5,690	23.3	0.845	98

[a] Refers to level of 60° L malt syrup.

firmness and stress-relaxation values increased while cohesiveness decreased with storage time. Firmness values also tended to decrease with higher levels of malt. With fresh bread, stickiness increased with higher levels of malt. This is consistent with previous studies by McDermott (1974).

DISCUSSION

Although various studies concerning the effects of processing conditions, ingredients, and loaf storage time on the properties of bread crumb have been published, measurements have been largely restricted to the determination of firmness. This has probably been partially due to the fact that firmness is the most meaningful and easily obtainable textural property. However, the use of instrumentation lacking the ability to measure a range of textural properties has also been a factor. The instrument described in the present article is relatively inexpensive to build (less than $5,000), compact, easy to use, and capable of measuring a wide range of textural properties. The use of the cam system provides precise control for repetitive measurements while allowing rapid change-over to other specified conditions. Because the instrument can perform measurements under conditions of constant deformation or constant force, a wide variety of textural properties can be measured. Additionally, the fact that the compression rate is linear (and variable) provides force-time curves that are directly related to force-compression, allowing easy interpretation of data.

The use of the GRL compression tester has been demonstrated for the textural measurements of bread-crumb characteristics using conditions of constant compression. The use of this instrument under conditions of constant force for testing spaghetti properties is described elsewhere (Dexter et al 1982).

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