“Degree of Elasticity” Determination in Solid Foods

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ABSTRACT

Specimens of a variety of foods (banana, cheese, frankfurter, jelly candy, marshmallow, and potato) were subjected to four compression-decompression cycles at two prefailure deformation levels (12.5–15 and 20–25%). Total and percent recoverable work in each cycle were determined using a universal testing machine interfaced with a computer. The magnitude of recoverable work, its strain dependency and response to successive cycles were characteristic of each material. Percent recoverable work was unrelated, however, to strength (stress at failure), deformability, and stiffness. The general level of recoverable work was about 60–80% of total work in the materials commonly considered “elastic” and 20–50% in those known as “plastic.”

INTRODUCTION

THE TERM ‘elasticity’ refers to the ability to return to the original state. In its mechanical-textural context it is the property of returning to the original shape after being subjected to deformation. Although it is easy to distinguish between highly elastic (e.g. rubbery) and nonelastic (e.g. plastic) food materials, most foods have “intermediate elasticity,” that is they are elastic to some degree. Expressing this degree of elasticity in quantitative terms is not simple for conceptual and methodological reasons. In food research, elastic properties have been defined in different ways. In the Instron version of the instrumental Texture Profile Analysis (Bourne, 1968), “elasticity” or “springiness” is defined as total deformation of the specimen in the second “bite” and is expressed in length units. The “degree of elasticity” has been defined as the ratio between recoverable and total compressive deformation (Mohsenin, 1986; Olkku and Sherman, 1979) or, as a percentage,

$$\text{Degree of elasticity} = \frac{\text{Recoverable deformation} \times 100}{\text{Total deformation}} \qquad (1)$$

The problem with this definition is that technically it is often difficult to determine exactly the recoverable deformation. The problem is compounded with viscoelastic foods where some recovery is retarded, thus introducing a time element into the determination. A way to bypass the difficulty of determining the recoverable deformation and to reduce the error due to retarded deformation is to define the degree of elasticity in terms of the ratio between recoverable and total *work* (Olkku and Sherman, 1979) i.e.,

$$\text{Degree of Elasticity} = \%\ \text{Recoverable work} \qquad (2)$$
$$= \frac{\text{Recoverable work} \times 100}{\text{Total work}}$$

Since work is measured as the area under the force-deformation or stress-strain curve, the error is negligible that stems from the uncertain location of the recoverable deformation or strain (Fig. 1). When the total and recoverable work are calculated from areas under the stress-strain curves their units are: work/unit volume of material. Since, as previously mentioned, most foods are not truly elastic nor totally plastic, their determined “degree of elasticity” using eq. (1) or (2) may be strain dependent. This dependency itself can be treated as a textural characteristic of the food since it reflects on the structural changes induced by deformation.

Until recently, determination of the “degree of elasticity”, defined by Eq. (2), had been cumbersome. This was primarily because area measurement was inconvenient and required retrieval and processing of a large amount of data. Therefore, experimental values of the “degree of elasticity” have rarely been reported on the foods (Torres et al., 1978; Olkku and Sherman, 1979; Lee et al., 1983; Mohsenin, 1986) and solid foods have been mainly characterized by their strength (the stress at failure) and stiffness. The latter is the material’s resistance to deformation (Marin, 1962) and is expressed by Younge’s modulus in elastic materials and by the “modulus of deformability” in solid foods that deviate from ideal elasticity (Mohsenin and Mittal, 1977).

The situation has drastically changed recently with introduction of testing machines interfaced with computers. Data acquisition, parameters, transformation and integration procedures are part of, or can be incorporated into software. Consequently, calculation of “degree of elasticity” using Eq. (2) can be done with relative ease and, with the appropriate program, in a very short time.

The objective of our work was to determine the “degree of elasticity” of various common foods in compression-decompression tests and to demonstrate how its magnitude is affected by strain level and number of cycles imposed.

MATERIALS & METHODS

POTATOES, bananas, cheddar cheese (Kraft), Monterey jack cheese (Kraft), skinless franks (Grote and Weigel), jelly candy (Sweet Life)

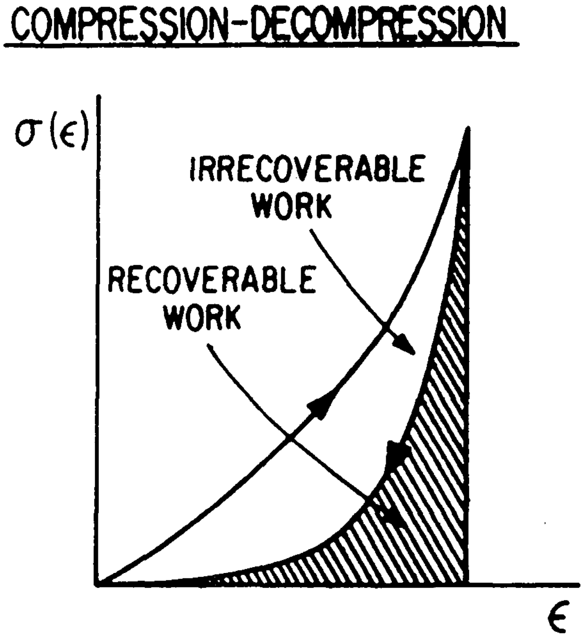

Fig. 1—Schematic presentation of stress-strain relationships in single compression-decompression cycle where the end of the decompression curve hardly enables exact determination of the recoverable strain.

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Table 1—Mechanical properties of various solid foods

	Stress at failure[a]		Deformation at failure		Modulus of deformability[b]		Range of linear stress strain relationship (% deformation)	
	Mean[c] (kPa)	COV[d] (%)	Mean[c] (%)	COV[d] (%)	Mean[c] (kPa)	COV[d] (%)	Mean[c] (%)	COV[d] (%)
Banana flesh	17	3	19	9	140	5	6	7
Cheese:								
Cheddar	43	4	26	3	280	6	8	14
Monterey	28	12	47	8	90	14	8	20
Frankfurter	70	5	52	4	70	6	31	10
Jelly candy	190	5	50	4	280	7	44	6
Marshmallow	9	7	-	-	8	10	41	10
Potato flesh	970	4	34	8	3,100	9	14	10

[a] Also defined as compressive strength.

[b] A measure of stiffness.

[c] Determined from 4-5 replicates.

[d] COV is the coefficient of variation calculated as 100 $\sigma/\bar{x}$.

and marshmallows (Kraft) were purchased in a local supermarket. Cylindrical specimens with nominal dimensions (1.5 cm × 1.5 cm) were prepared from the potatoes, bananas and cheese using a cork borer and a pair of parallel blades. Exact dimensions of each specimen were determined using calipers. Skinless franks were trimmed with the parallel blades and marshmallows were tested "as is". Their dimensions were 1.5 cm 1 × 2.1 cm diam and 3.3 cm 1 × 3.1 cm diam, respectively. Mechanical tests were performed at ambient temperature (25 ± 1°C).

Mechanical tests were performed with a universal testing machine (Instron Model 1000, Instron Corp., Canton, MA) in two compression modes. In one they were uniaxially compressed to failure, between two lubricated flat plates, at speed 10 mm/min, to determine stress and strain at failure. In the second all but the cheddar cheese and banana were subjected to four successive compression-decompression cycles to predetermined deformation levels of 15 or 25%. Banana specimens were compressed to 12.5 or 17.5% deformation, and cheddar cheese to 15 or 20%. These levels were selected so the failure region would be avoided. Crosshead speed in both directions was also 10 mm/min.

The universal testing machine was connected to a computer (Macintosh II, Apple Computer, Inc., Cupertino, CA) by an analog to digital conversion interface card. The crosshead movements were controlled through the computer with a specially developed program. In the case of compression-decompression cycles, first one command was given to compress to the preset percent deformation and then another, to start a new cycle. The initial height of the specimen in the first cycle was determined automatically when a threshold voltage (force) was detected. At the end of each cycle the crosshead returned to its original starting location and a new cycle was started from that position. The program also acquired data from the testing machine for conversion of the continuous voltage vs time output into digitized, corrected stress: $\sigma_{cor}(t)$, versus Hencky's strain, $\epsilon_H(t)$, relationships (Marin, 1962; Calzada and Peleg, 1978; Rebouillat and Peleg, 1988) defined as:

$$\sigma_{cor}(t) = \frac{F(t)\,[H_o - \Delta H(t)]}{A_o H_o} \qquad (3)$$

and

$$\epsilon_H(t) = \ln\left[\frac{H_o}{H_o - \Delta H(t)}\right] \qquad (4)$$

where F(t) is the momentary force, H_o is the initial specimen length, $\Delta H(t)$ the momentary absolute deformation, and A_o the cross-sectional area of the original specimen.

In the first type compression tests the slope of the linear portion of the stress-strain relationship was defined as the deformability modulus, E_D, which was calculated by (Rebouillat and Peleg, 1988):

$$E_D = \frac{\sigma_{cor}(t)}{\epsilon_H(t)} \qquad (5)$$

It has stress units and can be treated as a measure of stiffness (Marin, 1962). The range of the linear portion of the stress-strain relationship was determined by successive linear regressions until the magnitude of the regression coefficient (r^2) started to decline.

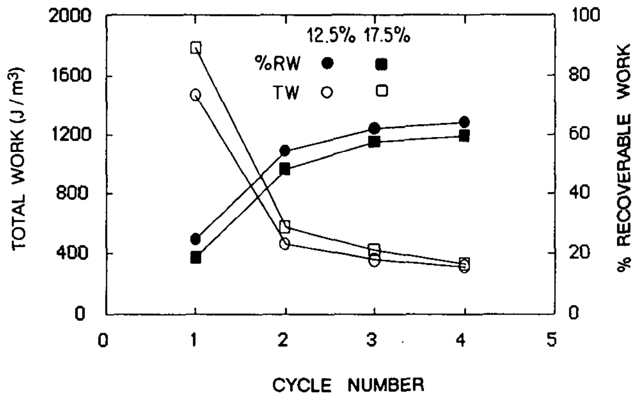

Fig. 2—Total and percent recoverable work of ripe banana flesh in four successive compression-decompression cycles at two strain levels.

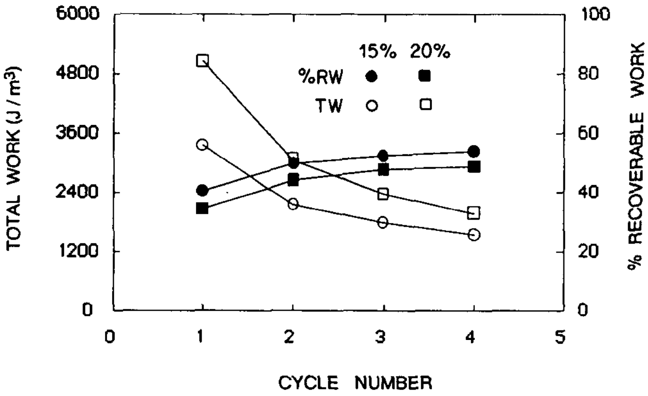

Fig. 3—Total and percent recoverable work of cheddar cheese in four successive compression-decompression cycles at two strain levels.

In compression-decompression cycles, the areas under the corrected stress vs Hencky's strain curves were also determined by the computer program using a trapezoidal method. The area under the compression curve was reported as total work/unit volume, while the area under the decompression curve was the percent of total work. All the reported results were means of 4–5 replicates.

RESULTS & DISCUSSION

SELECTED conventional mechanical properties of tested materials, are reported in Table 1. They had a very wide range of compressive strength (stress at failure 9–970 kPa), deformability (19–52% deformation at failure) and stiffness (deformability modulus 8–3, 100 kPa). Their compressive and percent

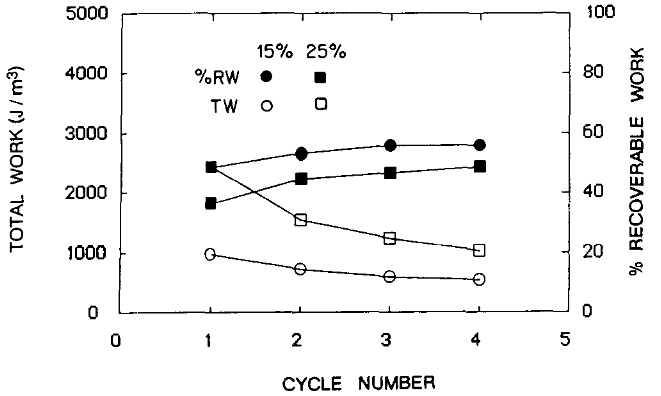

Fig. 4—Total and percent recoverable work of Monterey cheese in four successive compression-decompression cycles at two strain levels.

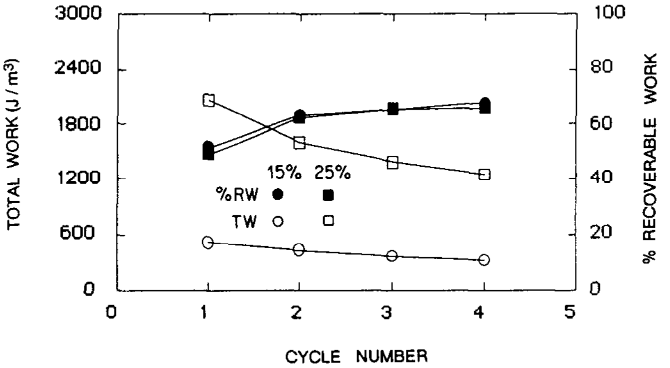

Fig. 5—Total and percent recoverable work of skinless frankfurters in four successive compression-decompression cycles at two strain levels.

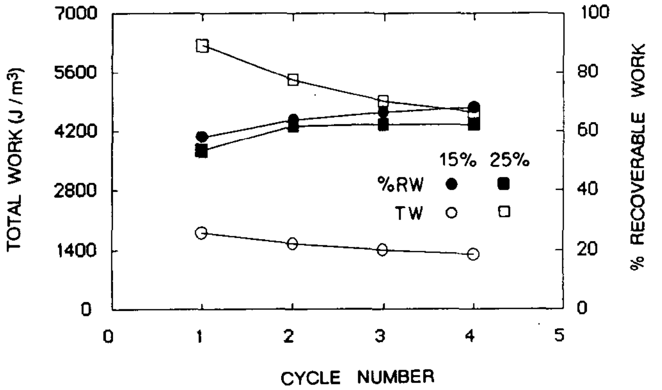

Fig. 6—Total and percent recoverable work of jelly candy in four successive compression-decompression cycles at two strain levels.

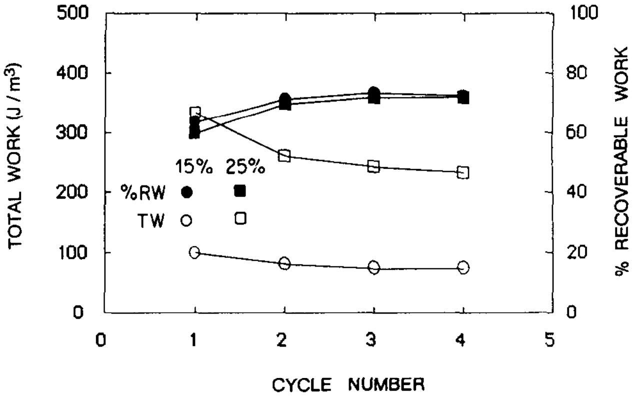

Fig. 7—Total and percent recoverable work of marshmallow in four successive compression-decompression cycles at two strain levels.

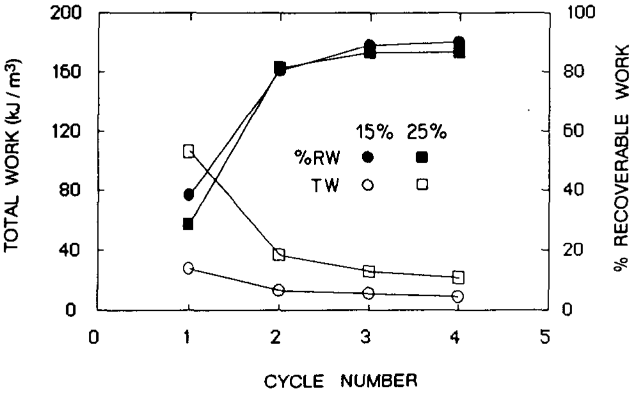

Fig. 8—Total and percent recoverable work of potato flesh in four successive compression-decompression cycles at two strain levels.

recoverable work, at two strain levels in four successive compression-decompression cycles, are shown in Fig. 2 through 8. By definition, the tougher materials can resist more for deformation. Therefore, the total work data of the first cycle were to some extent redundant. The figures show what cannot be derived from the tabulated data, i.e. how the total work changed as the specimen was subjected to successive deformation cycles. In banana, for example, there is a very steep decrease in work magnitude indicating irrecoverable structural disintegration even at 12.5% deformation. To a lesser extent this was observed in the other materials especially at higher deformation levels, e.g. Monterey cheese (Fig. 4), potato (Fig. 8) and most notably in cheddar cheese (Fig. 3).

As can clearly be seen in the figures, recoverable work vs cycle number was almost a mirror image of total work. This was because the material compressed in subsequent cycles, became progressively more compact and consequently stiffer and more elastic than the original structure. This behavior is not unusual and has been observed in other food and non-food materials when subjected to cyclical loading (Mohsenin, 1986).

Comparison between the different foods shows that those considered "elastic" under a relatively small deformation, e.g. frankfurter, jelly candy and marshmallow, had relatively high "degree of elasticity" in terms of percent recoverable work (i.e. 60–80%). This was also hardly affected by subsequent compression cycles. In contrast, those known as "plastic," notably banana and cheese, had, in their natural form (1st cycle), very low "degree of elasticity," i.e. about 20–50% recoverable work. Therefore, apparently percent recoverable work in successive compression-decompression cycles could serve as an indicator of degree of elasticity. However, since the recoverable work magnitude was strain dependent and the nature of the dependency was different in each material, it would be advisable to perform the test with at least two deformation levels.

There was no relationship between % recoverable work and strength, deformability or stiffness (Table 1). This indicated that "degree of elasticity" is a material property that should be determined separately to characterize texture of solid foods.

The calculation of total and recoverable work was based on normalized parameters (stresses and strains) and their magnitude, therefore, it should be independent of specimen dimensions. Conceivably, however, in certain materials a dependency on the sample diameter may exist and the same applies to deformation rate. If such dependencies are of practical significance, the same testing procedure can still be followed either with particularly relevant specimen dimensions and deformation rate or with a set of specimen dimensions and different rates.

CONCLUSIONS

IN GENERAL, "degree of elasticity" of materials can be characterized by the magnitude of the recoverable work fraction in the first compression-decompression. Thus, ripe banana flesh, known to be plastic, had a recoverable work level around 20% while the "elastic" frankfurter and marshmallow were at least 50–60%. As long as the deformation did not reach the failure level, a relative "degree of elasticity" could be established at any preselected strain. In theory all materials could exhibit a different, probably higher, "degree of elasticity" if tested at smaller strains, i.e. around 1%. Such measurements, however, require a very accurate instrument and an extremely elaborate specimen preparation procedure not feasible for testing food. It therefore appears that a selection of one or two strain levels in the range 10–25% is sufficient to provide a relative, if not absolute, measure of solid foods elasticity. Invariably, "degree of elasticity" increases with number of compression-decompression cycles while total work decreases. Both occur at a relatively low rate in elastic materials. In contrast, the changes were quite dramatic in the other materials (notably, banana, cheddar cheese and potato flesh) and were a manifestation of compaction. Thus, the magnitude of recoverable work fraction in the 2nd to 4th cycles was a measure of the compacted material's elasticity and not that of the original material. It is a characteristic of the material, however, and should be treated as an objective textural property.

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Ms received 9/6/90; revised 12/14/90; accepted 1/24/91.

Contribution of the Massachusetts Agricultural Experiment Station in Amherst. We express thanks to Mr. R.J. Grant for his graphical aid. Mention of commercial products does not imply endorsement over other products.

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tidases. The latter may hydrolyze peptides responsible for bitterness in the cheese. The addition of heat-shocked lactobacilli also permits simultaneous increase of the proteolytic enzymes and other enzyme systems supposedly responsible for conversion of proteolysis products to flavor components.

The heat-shock method is a simple and suitable method for augmenting the proteolytic enzyme system without interfering with cheesemaking. In addition, the technique represents no legal barrier or technological complications, because it may be achieved in a pasteurization unit which is available in most cheesemaking factories.

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Ms received 5/9/90; revised 9/10/90; accepted 1/24/91.