Optimum Stress Relaxation Test Conditions for Beef Products

G. S. MITTAL, M. ZHANG and S. BARBUT

School of Engineering, University of Guelph, Guelph, Ontario, Canada, N1G2W1.

SUMMARY: The effects of various test parameters on stress relaxation data for beef products, and the suitability of different models to describe the test data were investigated. One beef product from each of the three broad classes were taken - finely comminuted (frankfurter), ground beef (hamburger), and whole muscle (corned beef). Cylindrical specimens of meat products, 10, 15 or 20 mm in diameter and 10 mm in length were prepared. These were compressed to 10%, 20% or 30% of their original height for 9 min. The data was fitted in three models - Maxwell model with two elements, and Peleg (1979) and Nussinovitch et al. (1989) models. The stress relaxation test data was normalized by dividing the force by cross sectional sample area and strain to get modulus values. Both sample size and compression ratio affected model parameters. A diameter to length ratio (D/L) of 1.5 and any compression ratio were suitable for muscle foods; D/L = 1.5 and 10% or 20% compression for ground beef; and D/L = 2 and 10% or 20% compression for finely comminuted (emulsified) foods were optimum test conditions.

INTRODUCTION: The objectives of this study were: (i) To evaluate the effects of various test conditions on stress relaxation data for three beef products - whole muscle, ground and finely comminuted (emulsified). (ii) To evaluate the suitability of various models to describe the test results. (iii) To standardize stress relaxation test parameters for various beef products.

MATERIALS and METHODS: Particular lots of frankfurter and corned beef were supplied by a local manufacturer. The ground meat was filled in a casing in the form of a salami. This provided uniform samples, without air bubbles. The products' compositions were:

	Water	Protein	fat	ash
Frankfurter	55.9	12.6	28.5	2.9
Ground beef	54.5	15.4	26.8	3.2
Corned beef	79.0	13.8	2.5	4.5

Cylindrical specimens of the products 10 mm, 15 mm and 20 mm in diameter and 10 mm in length were prepared by an electric slicer and suitable cork borers. Stress relaxation tests were performed on an Instron universal testing machine. Cross head speed was 5 cm/min. The specimen were compressed to 10%, 20% and 30% of their original height. The force-time curves were recorded on a chart recorder at a speed of 50 cm/min for the first 1 min and 2 cm/min for another 8 min. Five replications were taken for each treatment. The whole experiment was run twice. The data was normalized by dividing the force by cross sectional sample area and strain (compression ratio) to get modulus values.

MODELLING: The stress relaxation data has traditionally been described in terms of a discrete linear-Maxwell model (Mohsenin, 1986):

$$F(t) = E_o + \sum_{i=1}^{n} E_i e^{-\frac{t}{\tau_i}} \qquad (1)$$

where F(t), E_0 and E_i are the decaying parameters (modulus = stress/strain), τ_i relaxation times and t is time.

Equation 2 was reported by Nussinovitch *et al.* (1989) for describing the stress relaxation data. This is a simplification of equation 1.

$$\frac{F(t)}{F_0} = A_1 + A_2 e^{-\left(\frac{t}{10}\right)} + A_3 e^{-\left(\frac{t}{100}\right)} \qquad (2)$$

where F_0 is the initial force, F(t) the decaying force, A_1, A_2, and A_3 the dimensionless constants. The unit for t is second, and 10 and 100 are the fixed relaxation times in second.

Peleg (1979) used eqs. 3 and 4 for describing stress relaxation data:

$$Y(t) = \frac{F_0 - F(t)}{F_0} \qquad (3)$$

$$Y(t) = \frac{a \cdot b \cdot t}{1 + b \cdot t} \qquad (4)$$

where 'a' and 'b' are the constants. In the following discussion, model 1 consists of eq. 1, model 2 represents eq. 2, and model 3 composed of eqs. 3 and 4. The 'a' in model 3 denotes the amount of stress decay during relaxation and 'b' represents the 'rate' at which the stress relaxes. A higher 'b' value expresses a steeper descent of the relaxation curve toward the residual value (Peleg, 1979).

In model 1, functions Fo = E0 + E1 + E3 and σ = E1/τ1 + E2/τ2, the derivative of the stress relaxation curve at t = 0, was chosen for further statistical analysis.

The normalized experimental data was fitted in models 2 and 3 using General Linear model (GLM) procedure of the Statistical Analysis System (SAS, 1989). Model 1 was fitted using the method given by Mohsenin (1986) and the computer program of Rudra (1987).

<u>RESULTS and DISCUSSION</u>:
I <u>Frankfurter</u> (i) <u>Model 1</u>: Table 1 shows the influence of different treatments on the model parameters. At 30% compression, no variability was noted in E1 due to sample size variations. Similarly, sample size had no effect on E2 and Fo at 20% compression. No difference was noticed in E0 for different sample sizes at 10% and 20% compression. Sample size has not affected τ1 at 10% and 30% compression. However, it was higher for 30% compression compared to 10%. At 10% compression, sample size had no effect on σ. At other compression ratios, σ decreased with the increase in sample diameter. (ii) <u>Model 2</u>: The sample size and compression ratio did not affect the parameters of model 2, or this model may not be sensitive enough to provide the difference in the treatments. (iii) <u>Model 3</u>: Only 'b' was affected significantly by treatments.

Fig.1 shows the different stress relaxation curves of different sample sizes and compression ratios. Modulus values were higher at 30% compression than at 10% and 20%. The difference between different sample sizes was smallest at 20% compression. The recommended test conditions are: diameter/length ratio of 2 and 10% or 20% compression ratio.

II <u>Ground-beef</u> (i) <u>Model 1</u>: Table 2 indicates that in general E1 increased with the increase in D/L and compression ratio. Statistically, there was no effect of sample size for 10% and 30% compression. E2, Fo and τ1 increased with the increase in sample diameter for 10% and 20% compression. E2 decreased with the increase in sample diameter. There was no effect of sample diameter on τ1 for 30% compression. τ2 increased with the increase in compression ratio and sample diameter, except for treatment 2. The effect was more significant at 20% and 30% compression. E0 increased and σ decreased with the increase in compression ratio and sample diameter for 20% and 30% compression. (ii) <u>Model 2</u>: A1, A2 and Fo were influenced by treatments. Fo increased, generally, with the increase in sample diameter and

TABLE 1
DUNCAN'S RANKING OF MEAN VALUES OF TEST PARAMETERS FOR FRANKFURTER, THE E_1, E_2, E_0 AND F_0 ARE MODULUS IN kPa.

TREATMENT			E_1	E_2	E_0	τ_1, s	τ_2, s	F_0	σ, kPa/s
COMP =10 %	1	D/L=1	40.5 a b	54.0 b c	48.5 b c	561.6 d	8.68 c	143.0 b c d	6.53 b
	2	D/L= 1.5	32.3 a b c	44.2 d	41.6 c d	500.6 d	7.04 c	118.1 e	6.45 b
	3	D/L=2	22.4 e	56.2 b	48.4 b c	758.3 d	9.43 c	127.0 c d e	5.98 b
COMP =20 %	4	D/L=1	40.0 a b	48.4 b c d	38.2 d	575.4 d	7.36 c	126.6 c d e	6.86 b
	5	D/L= 1.5	26.2 d e	54.4 b c	43.6 b c d	1575 b c	14.8 c	127.2 d e	3.89 c
	6	D/L=2	30.9 c d	45.0 c d	36.9 d	1883 a	24.3 b	112.9 e	2.52 c d
COMP =30 %	7	D/L=1	38.7 a b c	88.2 a	50.9 b	873.7 c d	10.7 c	177.8 a	8.46 a
	8	D/L= 1.5	42.8 a	57.2 b	48.1 b c	1306 b c	26.2 b	148.2 b c	2.81 c d
	9	D/L=2	42.8 a	45.7 c d	64.7 a	1211 b c	36.5 a	153.2 b	1.73 d

Data with the same letter in a column are not significantly different at 95% level. D/L = sample diameter to length ratio, COMP = compression ratio.

TABLE 2
DUNCAN'S RANKING OF MEAN VALUES OF TEST PARAMETERS OF GROUND-BEEF. THE E_1, E_2, E_0 AND F_0 ARE MODULUS IN kPa.

TREATMENT			E_1	E_2	E_0	τ_1, s	τ_2, s	F_0	σ, kPa/s
COMP =10 %	1	D/L=1	24.1 c	30.1 e f	46.2 b c	214.9 c	6.74 d	100.3 b c	-5.24 c d e
	2	D/L= 1.5	30.0 b c	35.9 e	44.7 b c	274.6 c	5.71 d	110.5 b	-6.56 e
	3	D/L=2	27.4 b c	69.1 b	50.3 b	1190 a b	12.0 c d	146.8 a	-6.17 d e
COMP =20 %	4	D/L=1	24.2 c	27.8 e	28.6 e	383.9 c	7.1 d	80.6 c	-4.15 b c
	5	D/L= 1.5	32.8 b c	47.8 d	34.5 d e	927 b	11.6 c d	115.1 b	-5.07 c d
	6	D/L=2	46.6 a	50.3 d	58.9 a	1364 a	45 b	155.8 a	-1.29 a
COMP =30 %	7	D/L=1	40.0 a b	84.0 a	38.2 c d	1213 a b	17.4 c d	162.2 a	-6.08 d e
	8	D/L= 1.5	50.0 a	59.5 c	42.4 b c d	1191 a b	24.7 c	152.0 a	-3.11 b
	9	D/L=2	50.3 a	49.1 d	64.2 a	1442 a	66.4 a	164.6 a	-1.10 a

Data with the same letter in a column are not significantly different at 95% level. D/L = sample diameter to length ratio. COMP: compression ratio.

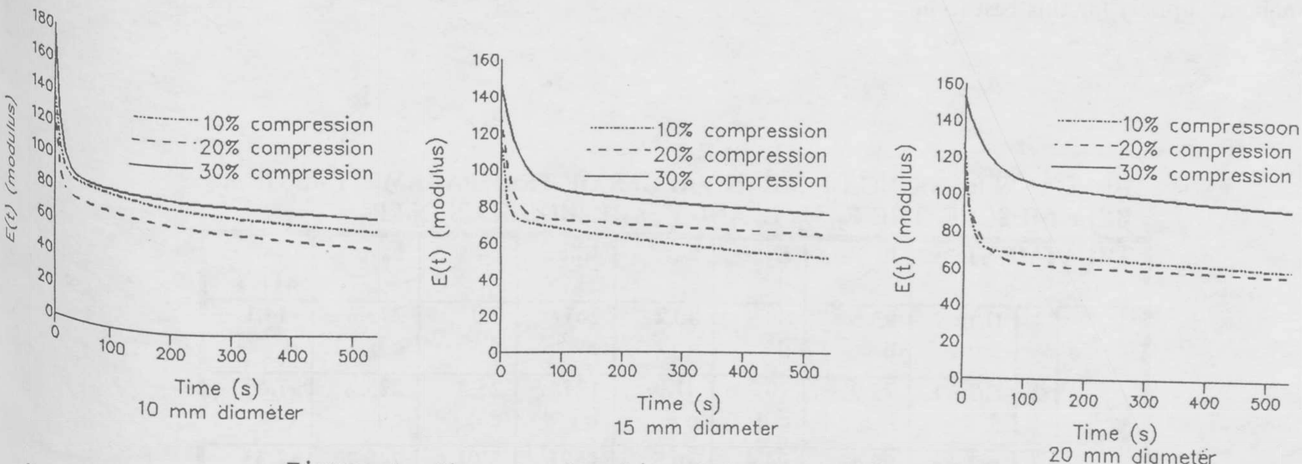

Figure 1. Stress relaxation data for various treatments for frankfurter, E(t) is kPa.

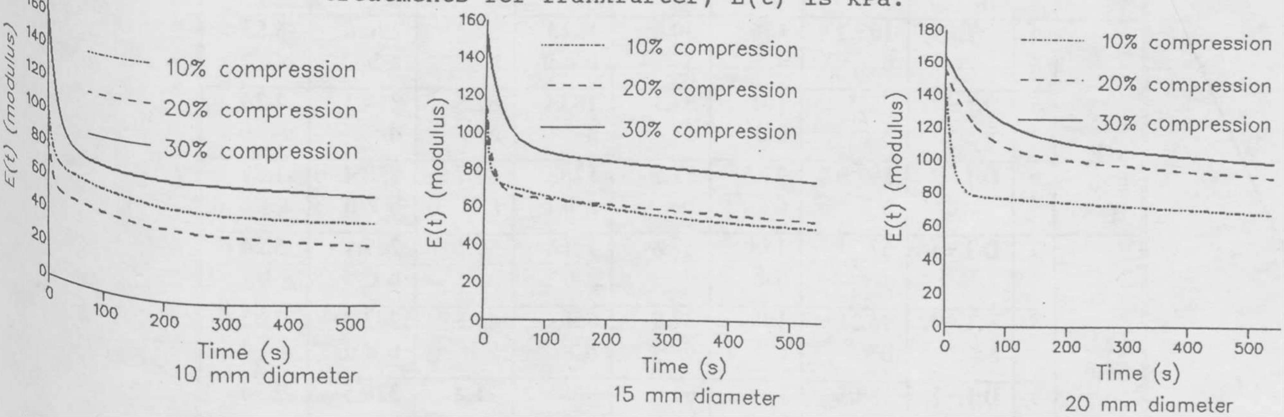

Figure 2. Stress relaxation data for various treatments for ground beef, E(t) is kPa.

compression ratio. (iii) Model 3: Treatment affected 'a' and 'Fo'. Fo increased with the increase in compression ratio and sample diameter.

Fig.2 shows the stress relaxation curves for different treatments. The recommended test conditions are: D/L = 1.5 and 10% or 20% compression ratio. It is important to provide the sample size and compression ratio when providing the information on stress relaxation test parameters. It is difficult to compare these parameters collected at various test conditions.

III Whole muscle (corned beef) (i) Model 1: Table 3 indicates that sample size has not influenced E1 for 10% and 20% compression. However, E1 and E2 increased with the increase in sample diameter for 30% compression. $\tau 1$ increased with the increase in sample diameter for 10% compression. In general, $\tau 2$ increased with the increase in test conditions, except for treatment 8. E0 increased with the increase in sample diameter for 10% compression. E0 also increased with the increase in compression ratio from 20% to 30%. For larger sample (D/L = 2), F0 increased with the increase in compression ratio. σ decreased with the increase in sample diameter for all compression ratios. (ii) Model 2: Only A1 and Fo were affected by treatments. Increase in sample size increased A1 for 20% and 30% compression. Fo increased with the increase in sample diameter from 15 mm to 20 mm. (iii) Model 3: Only 'a' and Fo were influenced by treatments.

Fig. 3 shows the stress relaxation curves for various treatments. The recommended test conditions are: D/L = 1.5 and compression ratio from 10% to 30%.

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TABLE 3

DUNCAN'S RANKING OF MEAN VALUES OF TEST PARAMETERS OF A BEEF MUSCLE. THE E_1, E_2, E_0 AND F_0 ARE MODULUS IN kPa.

TREATMENT			E_1	E_2	E_0	τ_1, s	τ_2, s	F_0	σ, kPa/s
COMP =10 %	1	D/L=1	93.5 b	89.9 d	80.2 a	261 e	7.9 d	272.6 c b	-14.1 d
	2	D/L=1.5	75.9 b c	107 c d	41.9 c d	1216 b c d	25.8 c d	225.2 c d	-7.40 c
	3	D/L=2	99.4 b	94.4 d	46.5 b c d	1591 a b	59.1 a	240.2 b c d	-2.35 a
COMP =20 %	4	D/L=1	103.7 b	156 a	30.6 d	1123 b c d	32.2 b c	290.6 a b	-6.53 b c
	5	D/L=1.5	76.3 b c	101 c d	33.1 d	1833 a	62.5 a	210.3 d	-2.26 a
	6	D/L=2	107.8 b	93.3 d	57.3 b c	1288 a b c	67.7 a	258.4 b c d	-1.71 a
COMP =30 %	7	D/L=1	62.1 c	148 a b	37.8 d	1466 a b	59.1 a	247.7 b c d	-3.24 a b
	8	D/L=1.5	96.3 b	109 c d	37.0 d	658 d e	48.1 a b	242.3 b c d	-2.83 a
	9	D/L=2	138.5 a	129 b c	61.0 b	808 c d e	71.4 a	328.5 a	-2.14 a

Data with the same letter in a column are not significantly different at 95% level. D/L = sample diameter to length ratio.
COMP: compression ratio.

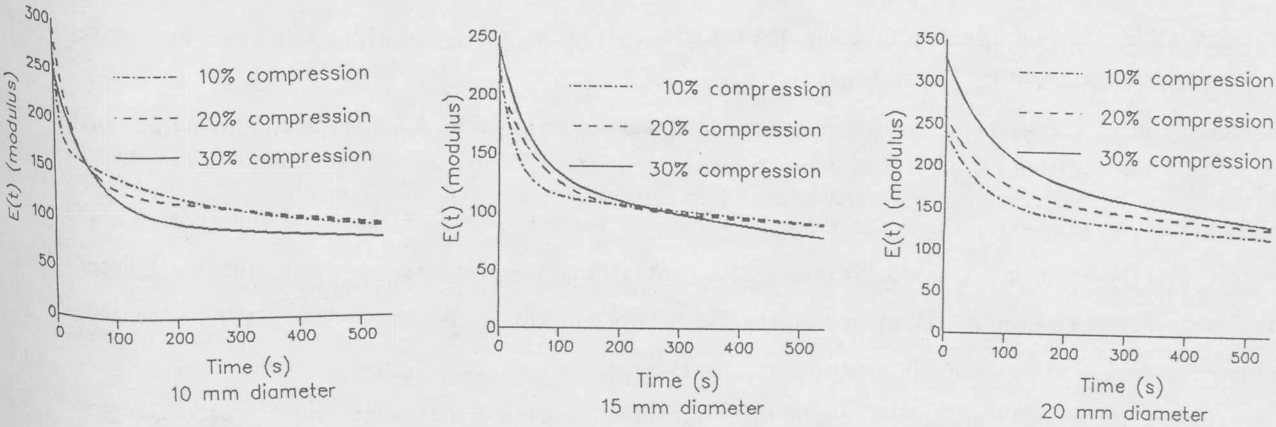

Figure 3. Stress relaxation data for various treatments for beef muscle, E(t) is kPa.