

Instrumental Texture Measurements for Processed Meat Products

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Introduction

Almost every issue of any technical food journal that publishes on meat contains articles with texture in the title or those that include some form of texture data. Generally, the data reported is from some form of cutting test, such as the Warner-Bratzler Tenderometer (e.g., Calkins et al., 1987), a punch test (e.g., Segars et al., 1975) or axial compression between two parallel surfaces (e.g., Foegeding and Ramsey, 1987). In each case, the specimen is deformed until there is rupture of fibers or, in the case of processed comminuted products, it may be rupture of a continuous matrix. Often, the only value retained is the force causing the rupture. This may be sufficient in some cases but if instrumental texture is to be more fully specified, a measure of deformability independent of the rupture force is needed. Area under a force-deformation curve can sometimes be a useful substitute for force or deformation since it is a function of both of these. Food texture, similar to mechanical properties of structural materials, can be better specified with 2 independent measurements than a single one. This is not to say that the 2 measurements are not both dependent on the basic structure of the food. It is simply that they may be affected differently and relate to different aspects of sensory texture.

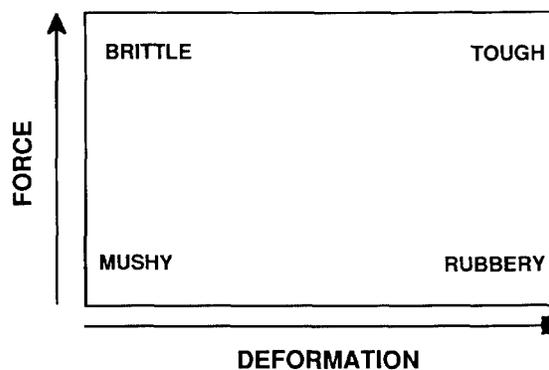
Meat toughness can be thought of as dependent on both force and deformation (Figure 1). Toughness, when used for structural materials, is defined as the energy that can be absorbed prior to fracturing (Polakowski and Rippling, 1966). This is also the concept of toughness in foods. In sensory texture profiling, the note toughness may be omitted because it is a combination of two other notes, hardness (force required to bite through) and cohesiveness (deformation by

the teeth before rupture). Toughness by itself may not adequately describe the texture because it is not specified how much of the toughness sensation is due to force and how much is due to deformation. The challenge in both descriptive sensory and instrumental texture evaluations is to measure truly meaningful parameters, which implies a minimum of redundancy. This is not easy to do. For example, in a recent paper (Hamann and Lanier, 1987) we were able to show that for highly cohesive muscle gels, tested by punch penetration in the end of a cylindrical specimen, punch rupture force and punch rupture deformation were not independent measurements because complex shape changes in the specimen due to force greatly influenced the deformation measurement.

Fundamental Instrumental Texture Measurement

The best way to insure that we are making independent measurements of different textural parameters is to understand the test we are using so we can make accurate assumptions. This is not always possible but can be done in the case of processed meats when the specimen is quite homogenous and isotropic (properties independent of orientation). We have investigated this quite thoroughly (Hamann, 1987; Hamann and Lanier, 1987; Montejano et al., 1983; Montejano et al., 1984) and found that a twisting test has worked well for products, including frankfurters. The advan-

Figure 1



Suggested Relationship of Sensory Textural Descriptors to Measurements of Rupture Force and Deformation (modified from Lanier, 1986).

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tages are that the specimen does not change volume or shape appreciably during the test so torque and angle of twist at rupture are related only by mechanical properties of the product matrix. From torque, a unit shear force (shear stress) can be calculated and from angle of twist, a unit shear deformation (shear strain). These stress and strain values are properties of the food and independent of the specimen size and shape. Test equipment is not expensive and procedures and computations are relatively simple (Lanier et al., 1985). For our specific situation, the equations for calculations are:

$$\tau = 1580 \text{ (torque in instrument units)}$$

$$\text{SHEAR STRESS (Pa units)}$$

Step #1

$$\gamma = 0.150 \text{ (chart travel/chart vel.)} - 0.00848 \text{ (inst. torque)}$$

Step #2

$$\gamma_{\text{true}} = \ln[1 + \gamma^{2/2} + \gamma(1 + \gamma^{2/4})^{1/2}]$$

If a food is only moderately cohesive so the value of shear strain does not exceed about 1.2, we have shown that rupture shear stress and strain calculated from axial compression by lubricated plates are not significantly different from those obtained from the torsion test (Hamann, 1983). This gives us considerable confidence that our analysis of what is occurring during the test is correct. At shear strains higher than about 1.2, axial compression shear stresses and strains are exaggerated because of excessive change in shape of the specimen that cannot be easily compensated for. Frankfurters that have a cohesive, springy texture rupture at torsion shear strains up to about 1.5 (Saliba et al., 1987). At this level, apparent shear strains calculated from axial compression were about 10% higher and shear stresses were about 6% higher. It would seem that for frankfurters

rupturing at shear strains below 1.5, either torsion or axial compression testing can be used and results would correlate about equally well with sensory texture. However, numerical values from the axial compression tests would be slightly higher. It needs to be emphasized that axial compression tests can produce quite different results depending on whether the ends of the specimen in contact with the compression plates are lubricated or not (Christianson et al., 1985). In the present article, when shear stresses and strains are calculated from axial compression tests the specimen ends were lubricated. Also, when the terms stress and strain are used, the meaning is shear stress at failure or shear strain at failure unless otherwise specified.

Usefulness of Instrumental Results

We will discuss relationships directly applicable to processed meats, but I believe the principles are general. Our sensory terminology is that of the descriptive texture profile method (Szczesniak, 1963) as applied to meat products (e.g., Berry et al., 1987). Comparison will also be made with the empirical Instron Texture Profile (TPA) method (Bourne, 1978) which utilizes the terminology of the sensory profile and is based on two compressions of a sample to a specific post-rupture thickness between two flat surfaces.

To establish how well selected rheological tests correlated with human sensory evaluations, Montejano et al. (1985) compared torsion and TPA results with sensory results for 8 protein gels. Five of these were low fat muscle gels (beef, pork, turkey and 2 fish). Three were egg white. Shear strains at rupture ranged from 1.2 to 2.8. Table 1 gives correlations between sensory notes and instrumental parameters. It is immediately obvious that strain and TPA cohesiveness correlate strongly with the first 6 sensory notes. The paper further shows that these 2 instrumental parameters correlated strongly with each other ($R=0.83$) as did the 6 sensory

Table 1. Correlation Coefficients for Sensory and Instrumental Texture Parameters of 8 Food Protein Gels¹. From Montejano et al. (1985)

Sensory note	Instrumental Parameter								
	Torsion shear stress	Torsion shear strain	Initial shear modulus	Hardness	50% comp.	Cohesiveness	Springiness	Gumminess	Chewiness
Springiness	0.62 ²	0.83	.- ³	0.61	0.42	0.79	0.66	0.68	0.70
Hardness	0.72	0.80	0.57	0.74	0.60	0.74	0.59	0.77	0.77
Cohesiveness	0.62	0.87	.-	0.61	.-	0.81	0.68	0.68	0.69
Denseness	0.48	0.80	.-	.-	.-	0.76	0.65	0.55	0.57
Chewiness	0.69	0.79	0.48	0.70	0.55	0.71	0.53	0.74	0.75
Gel persistence	0.49	0.77	.-	0.49	.-	0.76	0.65	0.56	0.58
Gumminess	.-	-0.60	.-	.-	.-	-0.56	-0.44	.-	.-
Adhesiveness	.-	-0.47	.-	.-	.-	.-	.-	.-	.-
Moisture release	.-	.-	0.44	.-	0.44	.-	.-	.-	.-
Coarseness	0.56	0.81	.-	0.57	.-	0.77	0.68	0.63	0.64
Graininess	-0.52	-0.83	.-	-0.53	.-	-0.77	-0.65	-0.60	-0.61
Cohesiveness of mass	.-	-0.69	.-	.-	.-	-0.67	-0.56	-0.46	-0.48
Particles	.-	.-	0.44	0.37	0.52	.-	-0.42	.-	.-

¹Number of observations used in calculating each coefficient was 144.

²Correlation coefficients ≥ 0.58 are significant at $P < 0.01$; coefficients ≥ 0.41 are significant at $P < 0.05$.

³Not significant.

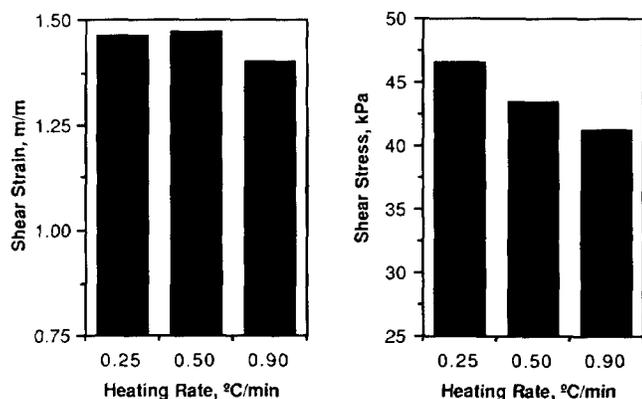
notes. Stress and TPA hardness correlated strongly with each other ($R=0.94$) but did not correlate as strongly with the sensory notes as did the parameters based on deformation to failure. An association of sensory notes similar to that shown in Table 1 and strong correlations with instrumental rupture force and rupture deformation have been shown in an extensive two-location study using a group of gels made from gelatin, pectin or K-carrageenan as primary gelling agents (Daget and Collyer, 1984). It appears that for gels, most of the mechanical type sensory notes are not independent and often can be best predicted by a deformation to rupture type instrumental parameter. This is consistent with the popular use of the folding test (degree of folding before a crack occurs) in the Japanese fish sausage industry to evaluate surimi functionality. We have shown in our laboratory that a shear strain of about 1.9 or greater is equivalent to passing this fold test (Lanier et al., 1985). The instrumental parameters in Table 1 based on measurements taken before rupture (initial shear modulus and 50% compression force) did not correlate as strongly with sensory notes.

The reason that so many of the sensory notes correlate with each other for these gel systems is that they exhibit a high degree of elasticity (a rapid high degree of shape recovery when the deforming stress is removed). This is what gives a frankfurter or similar food its springy character. Stress and strain tend to increase or decrease in a similar fashion so the ratio, shear modulus (or rigidity) will change less than either of the parameters used in its determination; hence the lower correlations with sensory notes. It must be cautioned that stress and strain do not always increase and decrease together and protein dilution, ingredient additions and process changes can affect stress and strain very differently.

Influences on Stress and Strain

It has been shown (Hamann, 1987) that rupture shear strain can be considered a primary measure of meat protein functionality in producing a cohesive product structure and it is usually not strongly influenced by ingredient additions, added water or changes in process schedule. On the other hand, stress is strongly influenced by these variables. For

Figure 2



Effects of Heating Rate on Torsion Rupture Properties of Frankfurters; protein: 7.8% pork, 5.2% beef (data from Saliba et al., 1987).

Table 2. Degree of Influence of Several Factors on Failure Stress and Strain of Processed Muscle Foods (S = strong, M = moderate, W = weak).

Factor	Stress	Strain
Protein Functionality	S ^a	S
Protein Concentration	S	W
Filler Ingredients	S	W
Thermal Process		
Heating Rate (slow heating values higher)	S-M	W
Final Cook Temperature		
red meat & turkey (low temp. values high)	S-M ^b	M
surimi (high temp. values higher)	M	W
30 min hold at 40°C before cook		
red meat (decreases values)	M-W	M-W
turkey (increases values)	W	W
surimi (increases values)	S-M	M-W

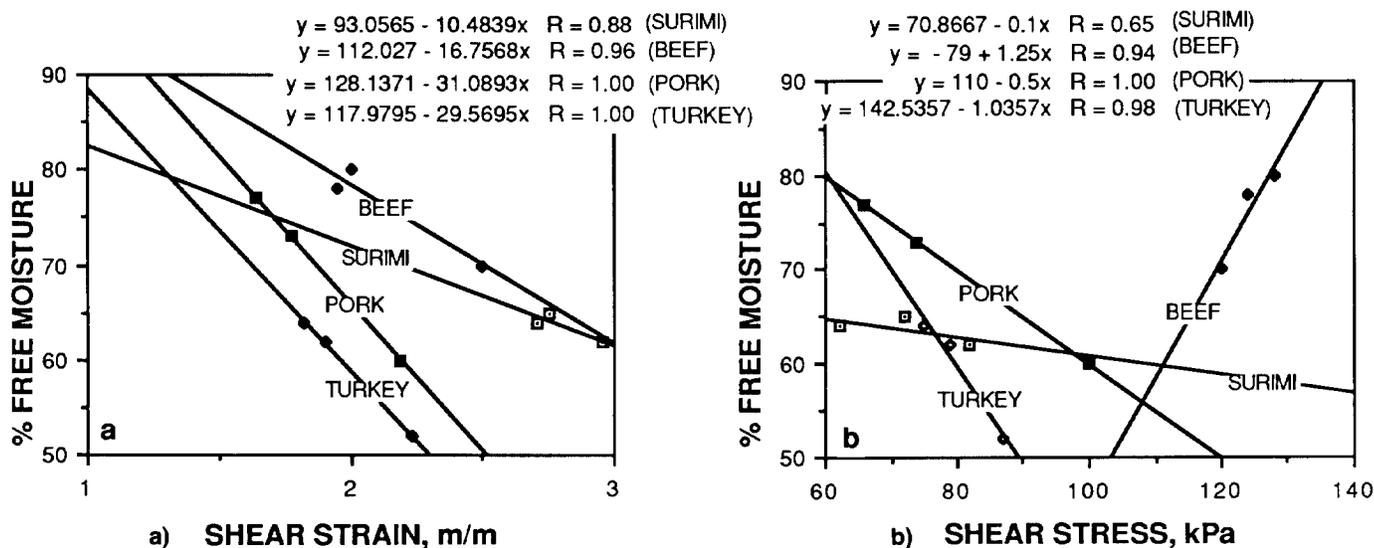
^aApplies to all species groups unless separations are shown under factor.

^bStress values for beef tend to increase with higher end point temperature, 60-90°C.

example, Saliba et al. (1987) studied heating rate affects on frankfurter properties (Figure 2). Note that stress was influenced much more, proportionately, than strain. In minced fish muscle gels, starch has a major influence on stress but little on strain (Wu et al., 1985). Table 2 summarizes general observations from published and unpublished studies done in our laboratory. Refinement of this table will occur as new data becomes available.

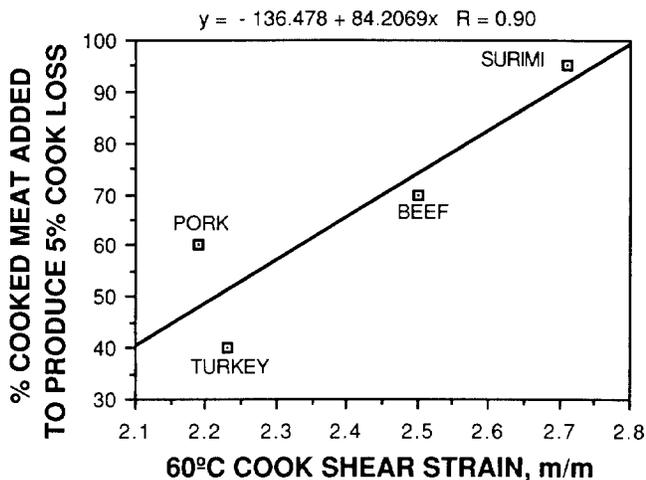
One recent study in our laboratory (Lanier, 1987a) has shown that there is a close relationship between water holding and strain and for red meats, final cook temperature is critical to both. In this study, minced muscles of 4 species (water soluble proteins removed from minced fish in the case of surimi) were compared using a model low fat formulation with a 5/1 water to protein ratio and 2% salt. Sols were heated using one of 3 schedules: 90°C/20 min, 40°C/30 min - 90°C/20 min, and 60°C/30 min. Measured variables were % free moisture using a press technique, torsion stress and strain. When free moisture was plotted vs strain, very high correlations were noted within species (Figure 3a). The highest strain values for each species were for the 60°C cook, except for surimi which was not strongly influenced and the 40/90 cook was better. Both beef and pork exhibited the lowest strains for the 40/90 cook. In all cases, however, higher strains were associated with lower free moisture although the slopes and intercepts of the lines were species-dependent. That a more cohesive product holds water more tightly is evident. When % free moisture was correlated with stress (Figure 3b), correlations were lower and line slopes were very different between species with the extreme being beef, for which the slope was negative (higher free moisture associated with higher stress). Hermansson (1979) has stated "There is a common misunderstanding that gel firmness and the water-binding of gels are correlated. This is not always the case. Soft gels with a fine network structure may have better water-binding properties than firm gels with a

Figure 3



Rupture Property-Free Moisture Relations for low fat model products made from 4 species; a) Shear Strain, b) Shear Stress (data from Lanier, 1987a).

Figure 4



Relation of Rupture Shear Strain and Species Cook-loss Tolerance of Denatured Meat (data from Lanier, 1987a).

coarser network structure." Figure 3b is consistent with this statement and further illustrates that several factors strongly influence rupture stress.

A second aspect of the work cited above (Lanier, 1987) was replacing functional meat with heat-denatured meat until the cook loss for the 60°C cook exceeded 5%. Figure 4 shows positions of the 4 materials on a graph of added denatured meat vs strain. Strain explains most of the tolerance of denatured meat.

Empirical Instruments

It is not possible in the space allotted here to discuss all of the factors affecting stress and/or strain. This has been done more thoroughly in another paper (Hamann, 1987). Let us think briefly, however, about the commonly used meat texture

instruments which we use but do not understand well enough to be able to calculate stress and strain values. In discussing Table 1, it was stated that TPA cohesiveness and hardness correlate well with strain and stress respectively. For processed meats, the TPA method is probably the best choice among the empirical methods.

The various blade or punch type instruments have their unique characteristics but also share the fact that there is a cutting action. We have evidence that, in general, the cutting or penetration force is proportional to rupture shear stress (Hamann, 1987; Hamann and Lanier, 1987; Lanier, 1987b) and thus influenced by the factors shown in Table 2. This seems to be true when in the literature I have been able to check. For example, Warner-Bratzler yield force values for beef semitendinosus muscle cores increased when end point temperature was raised from 60°C to 80°C (Moller, 1981) similar to what was found for shear stress for the model product of comminuted beef made by Lanier (1987a). Punch or blade deformation is not as well correlated with shear strain because change in specimen shape is a major part of the deformation and it depends on the punch or blade force and stiffness of the specimen, not just on the stress/strain relationship of the matrix. A challenge to those of us working in meat texture is to develop better methodology for evaluating cohesiveness of cooked intact muscle portions.

In this paper, I have emphasized that a shear force value or even a stress value does not by itself specify meat texture. Rupture shear strain in a model product is a good measure of cohesive structure forming functionality of comminuted muscle. It is also closely tied to water binding within yet to be determined category limits. Shear stress is a good measure of the effectiveness of added ingredients, process changes and protein concentration. The challenge of improved instrumental texture measuring methods for intact muscle is still before us. Perhaps we can use what we have learned concerning processed meats as a guide.

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Discussion

Session One

T. Bidner: Will you talk about strain, the deformity, and how these were measured in your research? You said they didn't correspond to Warner-Bratzler shear and Kramer shear results, so how have they been measured?

D. Hamann: The force values that you get from a Warner-Bratzler (in many cases that's all you take with a Warner-Bratzler; in some cases you do try to get deformation), I think, correlate with the stress value. They are going to provide similar information. The deformation and the work that we do on processed meats or comminuted products uses a twisting test where we do not change the shape of the product. Actually, we apply a twisting test where we do measure how much windup we get in the product. It doesn't really change shape or volume. Because of that, we are able to get two independent measurements, a deformability measurement that is not affected by the stress value and the stress value goes along with it. In most of the empirical measurements, what you have is a rather complex interaction between the two. We did a fairly detailed study on fish gels (surimi-type gels) over a couple of years and have shown that in punch tests, where we are punching into a cylinder of gel, that you are dealing with a fairly narrow range that punch deformation will correlate quite well with the strain value. If you have quite a bit of variation in your product, then the change of shape (due to the fact that it is stronger or weaker, force-wise) becomes a factor. What you are measuring, partly, with the

punch deformation is the change of shape. That dominates and so you cease to have an independent measurement. The two things, force and deformation, are telling you basically the same thing. I think the challenge right now in dealing with intact muscles is to come up with a test where we have both an independent strength or force value and an independent deformability value, because both, I think, are important in texture, at least from our sensory work. I don't have the answers on how to do that on intact muscle.

C. Calkins: Don, is it important for us to begin to define mathematically the stress and strain relationships in those empirical tests that we all frequently use?

Hamann: It is important from this standpoint. I think that when we get down to the processing plant and to the common usage, we need a quick test that gives some answers in quality control. We may be able to get to that point but we are really not there right now. I think from a research standpoint, however, it gets important to do this because what this enables us to do is use two different instruments, completely different in how they impress a force upon the product, and get the same answers. In fact, you can do this with hot dogs now; Dr. Foegeding, who is sitting over here, has done this to some degree, where you just make an axial compression test on a cylinder. If the strength is below about 1.2, which is a fairly low strain to failure, but your less rubbery hot dogs will fall in that range, you can get exactly the same stress and strain from a compression test that you get from the twisting test. The answers are not statistically different. However,