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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, when you start to have more deformable hot dogs, when you get up around 1.5 in shear strain, then you start to get differences due to the gross change of shape in the compression test. You want to add to that, Allen?

A. Foegeding: I guess the key point is that with surimi, it was too rubbery. You couldn't compress it to failure and you lose assumptions on change and deformation. Using an Instron with uniaxial compression and using equations that have been developed by Don Hamann, we can get very good stress and strain values, that is providing it fails within 80% compression.

B. Bach: Increases in the shear stress values and the shear strain values indicate increases in the binding of the components in meat products. Are there any different binding structures that distinguish different stress and strain values?

Hamann: I can't answer that directly. We do know that when the stress and the strain go up, we tend to have a more translucent gel in many of our products. That means there is less light scattering. That means that the matrix is compact with fewer surfaces of transition or change in product. For instance, the water is probably held in bigger cells, so to speak, and the solid matrix may be more continuous. In some of our SEM work, this seems to be the case, particularly in fish gels and egg gels where you have fairly pure systems in terms of protein type. In the seafood products, the translucency tends to give us higher stresses and particularly higher strains. In the surimi industry in Japan, they use a folding test where you take a half-dollar shape and fold it once and then fold it again; if it doesn't crack, that's the highest rating they give because it is the most rubbery. Those that do that the best tend to be the most translucent; also the strain at which you start passing that test is around 1.9. If you are up to a shear strain of about 1.9, you will pass that folding test. Below that, you will not. Generally, hot dogs will not pass it, the more rubbery fish products do. Structurally, I don't know.

D. Kropf: You were indicating that higher protein functionality was related to strong stress and strong strain. Is this as true for offal meat protein as it is for nonmeat protein and as it is for skeletal muscle protein?

Hamann: What we are talking about here is the definition of functionality. As I am using it today, it is the ability to form a cohesive gel-like structure and to some degree, how it holds water. Because we are talking about the basic physics of that type of a structure, what I have said will apply across the board. Now when we look at other aspects of functionality, such as fat binding and this type of thing, I am not really ready to say that the values that we measured here are going to correlate well with all the other aspects of functionality that we sometimes include in the definition of functionality. All I am really considering at this point is the ability of the protein to form a cohesive, deformable structure that will hold water and filler ingredients and still give us a pretty good texture. When you start getting into these other protein forms, that would change. The water holding is not complete and different proteins are going to respond in different ways, just like these different species would. So I think we have a lot to learn there.

Kropf: This may be related, some of the work by Li Chan indicates that hydrophobicity and solubility of proteins are the most important characteristics in binding. Have you separated these out and how they might be related to stress and strain?

Hamann: I am not going to get into the hydrophobicity. There may be some others that can add because I really am not qualified to answer that one. When we get into the other part of the question, which is the solubility, we have done enough studies to know that solubility is an important factor from the stress standpoint. It's not too important from the cohesive or the strain standpoint, because concentration effects do not affect that very much. We can have fairly dilute systems and still have a fairly nice cohesive structure. Solubility does affect the stress part of it.

J. Claus: I have three generally-related questions: (1) You are working with low fat meat batters, less than 5%. Is there any particular reason why you are working in that type of system? (2) How does the fat influence shear stress and strain? (3) How would you go about measuring the influence of fat at different levels in the meat batter?

Hamann: Again I defer to Dr. Foegeding who has done more using the same methodology with frankfurter batters than I have personally. He may want to comment on that later. But basically, we find that if the low fat properties are increased, the higher fat properties are also, basically. The fat has an effect, without a doubt, but if meat is functional in the gelling process where we are dealing with a 5% fat or lower, it seems to be functional in a higher fat system as well. The fat acts as some of these other ingredients that I talked about. It will have some effect on the properties but if meat is functional as a low fat gel, it seems to also be functional as a higher fat gel.

Foegeding: The fat increases the stress mainly. It doesn't have a whole lot of effect on the strain but going from 10% to 11% to about 26% fat, you get a significant increase in stress without any significant change in strain.

Hamann: So it acts like these filler ingredients do. The fat is a filler, of course the more fat you use, there are greater temperature effects too. The temperature effects get fairly large.

G. Trout: I have a question I asked you about a little bit earlier when you told me about methodology. There has been a reasonable amount of work done over the last five to ten years to look at gelation properties of myosin and see how different cell concentrations and pH affect that. Over the years, there have essentially been two, I would say, different methodologies used. One is to measure rigidity as a measure of the overall gel strength. Another is to measure the force to yield as a measure of gel strength. The reason I bring these two methodologies up is the fact that the papers that use a different methodology get completely different results. If you would examine the literature from a cursory point of view, you would say that the papers contradict each other in the sense that in some situations, you will find myosin has its greater gel strength at low ionic strength, and some papers will show the exact opposite at higher ionic strength. So could you comment about that?

Hamann: Since we talked at lunch, I was expecting that question. My answer is that rigidity, the ratio of stress to strain, is not strength. The ratio of force to deformation is not strength, it is rigidity. Rigidity does not relate very well to textural properties. If you look at the work of Samejima and a lot of the Japanese work, where they base it on rigidity, they have a change but it's not going to tell you a whole lot about texture. I am going to show you a slide that will show that. I used this particular slide at a seafood meeting in November in Alaska. The reason I use it is because it shows a great variation in functionality in some proteins but no change in rigidity. This is a surimi-based model product subjected to freeze-thaw cycles. This was some work done at our lab with surimi, which is the minced fish with water solubles taken out. We had the top quality over there at 0 freeze-thaw cycles and we went to 3 freeze-thaw cycles in the freezer and then 9 and then 15. Now the functionality in terms of the texture, was dropping all this time but the rigidity did not change. The reason for that, remember we said that the stress and the strain are both affected by functionality and in this particular example, they were affected to the same percentage. If you took stress to failure and strain to failure, actually they changed. But the ratio, whether it is low strain or high strain, whether it is breaking or nonbreaking, that ratio didn't change. What we see is an insignificant change in rigidity but a very large change in functionality because it has gone through 15 freeze-thaw cycles. In red meats, we found that the stress is affected more than the strain. Therefore, you do get a change, more change, in red meats but the change in rigidity is much smaller than breaking strength change. Over on the right hand side is a dilution effect; you can add water and see that it didn't make much difference in the strain; it made a big difference in the stress. Therefore, the rigidity dropped off.

A. Miller: Would you comment on the use of stress relaxation as a textural determinant for either or both intact and comminuted products?

Hamann: That's a good question. We have tried stress relaxation but the problem with stress relaxation is exactly what you see here. You are measuring rigidity and rigidity doesn't relate very well to functionality. I'm not going to say that stress relaxation will not tell you anything. I do think it will tell you something about the chemistry if you know enough about what the relationships are. But I think it is rather a complex area of study that right now we are not able to make much of a comment on. The real weakness of the system is that you are dealing with rigidity, which doesn't relate directly to product texture.

Miller: You were talking about comminuted products, but in the case of intact muscle, there is a different set of circumstances. In fact, work that we've done shows that, depending on the direction of fibers, you can get quite large differentiation in rigidity. Personally, I think there may be more application for stress relaxation in intact muscles. Do you have any experience with that?

Hamann: Not directly, but I would tend to agree with you on that. We've got to realize ourselves that we are dealing with two different types of products. With most of what I have presented here, we are dealing with homogeneous and isotropic products. Basically, they don't change much in properties from position to position and with orientation. However, when you get into intact muscles, you are dealing with a more designed structure from the standpoint that it is a more complex structure and the good Lord has designed it very precisely in that it is not isotropic and it is a very efficient design. Therefore, some of these tests that have been utilized to show differences and even the shear type tests, when you look at different peaks, and identify with different fibers, I think have value. I don't want to be negative in that area. I think you're right.

Trout: One thing you haven't mentioned much is the geometry of sample. You did point out that in doing the twist test that you use a dumbbell type shape but you didn't point out why. With all the other tests, such as tensile strength and penetration, it has been reported that geometry of the sample is important. How important is it and why?

Hamann: Any time we are dealing with an empirical type test where we really don't have a very good knowledge of what's happening in terms of the mathematics of the stress and strain condition of the specimen, specimen shape and specimen size have to be held as close to identical as you can possibly get because we aren't able to compensate for them. The reason we used the shape that we did in the torsion test is because it's always going to break at the narrowest or smallest cross-section and we know what the size is there. Therefore, we are able to compensate for some changes. One of the things I want to study in the next few months is just how much effect we do get from changing that cross-sectional size. One of our graduate students, Debbie Saliba, who worked under Dr. Foegeding, used a couple of different sizes. Most of her work was done with a little larger size dumbbell because the frankfurter batter was not quite so finely formed as some of our other materials. We get basically the same answer with both sizes but there was a slight difference in strain and I think I know why. I think it's in the mathematics. We compensated for the twist in the end sections that were not cut down with the same material rigidity values found in the reduced diameter section. When we got to looking, there is a case-hardening effect on those ends. You cook them in a tube and therefore rigidity is about twice as great on those end sections as it is in the cut-down part where you are taking off the heat denatured area right under the casing. Therefore, I didn't use the right correction numbers so we had a slight difference in the strain. We weren't quite sure why we were getting it at the time Debbie was doing her work so we need to run some more tests. I think we were different by about 5% or 8% or something like that between the two sizes. It was a mathematical correction factor, we thought we knew what we had, but we used a wrong number.

Y. Lee: Back to the question on the effect of fat on the shear stress. How did you mean that fat actually increases the shear stress? What temperature are you talking about?

Hamann: When we said that, we were talking about room temperature. At room temperature where we ran the tests, the fat increased the stress value. It did not have much effect on the strain value.

Foegeding: It increased the stress to failure measurement at room temperature. It increased rigidity development during heating.

Hamann: So the fat had a rigidity increasing effect, even at higher temperatures. I'm not sure we know why exactly or even close to why, but fat does tend to do that. It is an interesting aspect.

Trout: I have a follow-up on the question I asked before. You said that geometry wasn't uniform along the sample so you force failure right at a point. Is there any other geometry that you can think of in this particular situation that can be used?

Hamann: That question is a good question from the standpoint that there are some materials, particularly when you get into a nonhomogeneous type product like the restructured products, where you need to focus your attention on the bind area. I believe you are using tension; certainly, tension is probably not a bad way to go, but you probably need to keep your sample size consistent. The problem with tension is you have a large change of shape, it necks down, you are pulling on it and you do have the disadvantage that it has a change of shape. However, the tension test is a good test and it is probably a little easier to analyze mathematically than many others. If I was working a restructured product where you are binding the materials together with protein, I think a tension test is what I would choose. I might also comment in a related sense that if you are going to use the texture profile analysis instrumentally, (where you compress between flat plates, calculate a cohesiveness and hardness), we have found that the texture profile analysis cohesiveness correlates quite well with the strain to failure. Also, the hardness from the TPA correlates well with the stress. In fact, if I was not using the torsion test on a comminuted system, I think I would use the TPA analysis that was written up by Bourne in 1978 in *Food Technology*. It correlates quite well with the sensory attributes.

Session Two

C. Calkins: Well, I will start off. Again, I would like to ask the question that we discussed in the earlier session. Given the fact that, depending on the product and depending on the instrument, it may be important to separate stress vs. strain measurements, do we need to go now to all of the empirical instruments that we have and mathematically define those relationships so we know what we are actually measuring?

D. Hamann: In answer to that question, that would be nice but it is difficult. There have been some attempts to do this but the change of shape problems are fairly large and it is hard to follow along accurately mathematically. Compressing a cylindrical sample does and calculating strains and stresses from that, as long as the shear strain is not above 1.2 (which is about what an Oscar Mayer hot dog is), you can get the same answers from compressing a cylinder as you can from twisting. We found that they are not statistically different because we are able to analyze what's happening under that test well enough to know what is going on. Top grade surimi has to have a strain of about 2. In fact, when you get much above that, you have to compress it so much that you end up with a very thin layer that will bounce right back at you. It becomes almost like rubber and those you cannot analyze very well. You can do it in torsion, but not in axial compression because you can't calculate shear stress and strain. Tension would be a better way to go there. I think that we can do more in tension and understand fully what is going on. What I am saying is that it would be nice because the deformability factor, particularly in comminuted processed products, is the best way of measuring functionality if we define functionality as producing a cohesive matrix and, in general, it is going to hold water, too.

J. Acton: You mentioned TPA test, what is your opinion about a test such as the torsion-type test in relating it to sensory panel analyses? The TPA seems to be not ideal but has a lot more correlation to a lot of sensory characteristics.

Hamann: I'm glad you asked that because I have a slide on that. This is some work that we published in the *Journal of Texture Studies*. This is the torsion shear stress, this is the torsion shear strain, and we are using the correlations, R square values, and these are sensory notes. So for example, the torsion shear strain explained about 83% of the springiness. This is for eight gels by the way, three of them were egg white gels, the rest were comminuted muscle type gels. We found that the cohesiveness or the shear strain value correlated with all of the sensory parameters that would be in the mechanical category. When you start correlating the shear strain with cohesiveness, you end up with very high correlations. You can see that by how well each one of them correlates with the sensory parameters. In this particular case, the torsion shear stress and the hardness values from TPA were very close but they did not correlate quite as well with the sensory parameters. If I had to take one measurement from a frankfurter or other gel systems, I would go to a cohesiveness measurement in TPA or a shear strain value. I would prefer the shear strain value, but cohesiveness in TPA looks pretty good. I'm qualifying that because it has to be a fairly elastic product, some hot dogs or frankfurters that tend to be mushy would not work quite as well. These are fairly bouncy products.

Acton: I guess the point I was raising was that with the TPA analyses, you get out many different sensory definitions from one test. If you run, what was it, shear strain, you get how many notes?

Hamann: You have two parameters. However, if you look at the TPA test, really it only has about three parameters. The rest of them are multiplication parameters. We found for the gel type systems or the comminuted meat systems that the multiplication TPA parameters didn't correlate very well. They didn't change too much. So in the TPA values, you are dealing with hardness, cohesiveness and springiness. You only have three base TPA values. The rest of them are calculated.

Acton: I have one last question. I guess I don't know how to define this because I don't work in the engineering part of it. Suppose we back up to, let's say, ground particle size rather than a comminuted matrix type system. What kind or type of textural test would you recommend in that area?

Hamann: That's a good question and I am really not able to answer it in a precise way. In terms of mouthfeel, the grind size doesn't seem to affect the strain to failure very much. It does affect stress more. The other aspects of the mouthfeel, whether it is due to grind size or other parameters, we cannot really measure by mechanical means; it has to almost be a sensory way to get at graininess. We can tell a little bit from the TPA by how fine it breaks down when you crush it. You can't do that as well with the torsion test. In the original work by General Foods in this area, they call those geometric properties, the breakdown properties. There are some correlations between mechanical properties and those, but I think on a consistent basis right now, I wouldn't say that I can measure those.

Calkins: Perhaps you could explain to us about the importance of, when you do a textural profile analysis with multiple compression, completely compressing the sample the first time? Frequently, from the standpoint of logic, there is a question about that first compression not really representing what actually takes place in the mouth. Could you clarify a little the importance of being able to completely deform the sample on that first compression?

Hamann: The texture profile analysis instrumentally requires that you fracture or rupture the sample on the downward movement between two surfaces. So, you need to compress that sample adequately so that it actually cracks or fractures. When it comes back up, those fragments, or substructures, would come back up and that's what you compress the second time. The way it breaks is related to the cohesive nature of the structure and that's basically what you are measuring in that second compression. Therefore it is important that you do that the same every time, that you always compress to the same thickness and keep your sample size the same height. I might comment, too, that Ed Bagley of USDA in Peoria at the regional lab has done quite a bit of work on lubricating the plates used to compress starch products. It does make quite a bit of difference whether those are lubricated or not.

M. Dikeman: You had a graph showing the relationship of percent free moisture on some of these parameters. That was with the processed or protein system, I believe.

Hamann: Actually, it was a comminuted model product, the water protein ratio was accurately controlled at five parts water to one part protein by weight and the salt level was 2%.

Dikeman: You indicated earlier that it is a little bit dangerous maybe to extrapolate to an intact muscle system but, relating percent moisture and your model system to an intact system, would you care to extrapolate there?

Hamann: OK, I think that what we have seen here in comminuted systems, the basic principles, probably could be extended to intact systems. I've done quite a study of the literature in the area of shear and compression tests on fish muscles where you have more of a flaky type structure and you don't have the toughness parameter as a strong factor. In most of the literature, no matter how they did it, mechanical texture factors seemed to correlate fairly well with one parameter, which was the shear force. The place that they got into trouble was when they went into comminuted systems where the cohesiveness starts to build up. It's not quite that simple a system in the red meats area because we don't have flaky texture and the muscle is less or more deformable, as the case may be. I think we do need, in general, two parameters. One could be the deformability factor, but, I think it gets complicated in the sense that you're going to have multiple breaks, depending on which fibers are breaking. In the literature, we do see where we can identify some shear peaks with certain components. What I would like to see down the road is to take this as the beginning point, and start to work on a table something like I put up there. It would be a fairly complicated table because you are going to look at all components, the various fibers. We don't have an isotropic material. It has very strong directional properties and we need to incorporate that into our system which could be sort of a stepping-stone to more complex systems. But, right now, I think the Warner-Bratzler shear, the reason it works a lot of time, and even if you just use force, is that it correlates very well with our stress values, even for comminuted systems. If that's all you need, and many times that probably is all you need, it will work. The problem is that there are a lot of other factors that affect it as I showed. Therefore we aren't always aware of what the thermoprocess effect is or what some other effect is. Of course you can hold that constant, but are you holding everything constant? That's really the problem that comes in here. One of the things we might look at is what factors affect the stress values in a comminuted system and then try to hold as many of those constant when we go to an intact muscle system. That might have some merit. There are a lot of questions that you can raise by looking at just the comminuted data and I don't have the answers. I just can ask some of the questions.