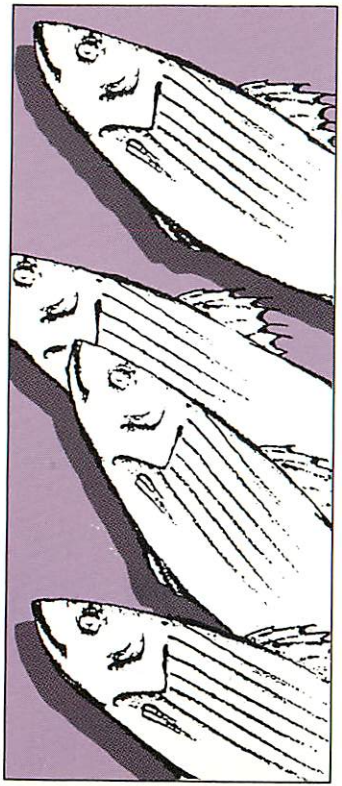
A Manual of Standard Methods for Measuring and Specifying the Properties of Surimi

Developed by the Technical Subcommittee,
The Surimi and Surimi Seafood Committee,
National Fisheries Institute, Washington, D.C.
for usage by the
United States Surimi and Surimi-based Foods Industries



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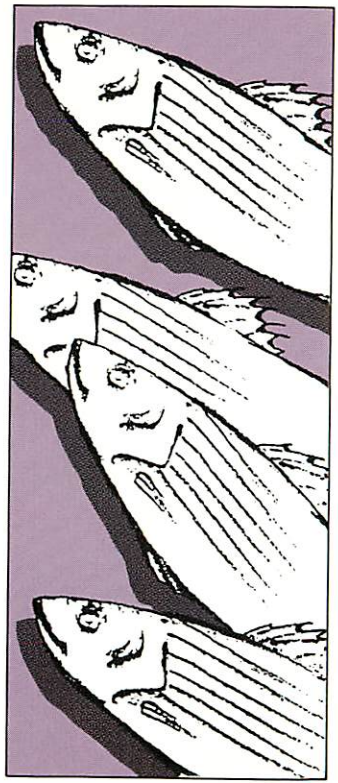

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U.S. Standard Testing Methods

INTRODUCTION

The Technical Subcommittee of the Surimi Committee of the National Fisheries Institute has developed testing procedures that will serve as "standard" or "benchmark" methods for evaluating and specifying the composition and functional properties of raw surimi in the United States. This standard testing regime has been extensively tested and shown to yield the most accurate measurements of any known test methods. These measurements are readily reproducible in any properly equipped laboratory, requiring only minimal training of the lab personnel (though careful attention to technique is required).

By using this standardized testing regime, the industry can accurately and objectively quantify and specify the quality of surimi for writing reliable buyer-seller contracts, for ensuring in-house quality control and for predicting surimi functionality in product manufacture (such as in least-cost formulation.

Non-standard methods of interest to surimi manufacturers and users are discussed in subsequent sections of this manual.

The subcommittee decided not to establish a grading system for surimi in conjunction with the development of standardized testing methods because these would be based on the quality criteria of only one user group. Rather, the quality of surimi should be specified by the manufacturer based

on the standard test measurements of individual lot samples. Each buyer or buyer group could then establish acceptable ranges (specifications) for each test property of interest. All properties may not be of interest to every processor.

Such specifications could be used to establish a pricing regime (quality grades) relevant to the application(s) of a buying group (such as the kamaboko or shellfish analog industry). This system should allow more flexibility for some surimi buyers who value certain properties over those valued by the food industry at large. For example, a "defect" such as red coloration might be viewed as a positive attribute by manufacturers of red meat products. This is one of the difficulties of the Japanese grading system. It downgrades the "quality" of surimi for any defect with respect to its use in kamaboko production.

Standard methods are described for measuring the properties of raw surimi determined to be important in formulating foods that are presently produced or that may include surimi in the future. Standard methods were established for both compositional and functional properties.

COMPOSITIONAL PROPERTIES

Compositional properties are chemical constituents measured as a mass or volume percentage of a unit quantity of surimi. In other words, each chemical constituent of surimi can be expressed on a percentage or concentration basis. The surimi constituents of interest to food processors are protein, moisture, fat and visual contaminants. Visual contaminants are colored/dark specks easily distinguished against the lighter muscle protein background. They are derived from fish belly lining, skin, etc. The measurement of non-visually detectable particulate contami-

nants, such as clear or light colored scale or bone, does not warrant a standard test procedure at present. Because pH is also a measurement of the concentration of a constituent (hydrogen ions), its measurement is included as a compositional property despite its primary use as an indirect measurement of functionality (gel-forming ability).

Protein Content To determine protein content, use the standard AOAC (1984) Kjeldahl digestion, distillation and titration procedures for nitrogen determination. The conversion factor 6.25 is used to convert percent nitrogen to percent protein. However, in species or products that contain substantial amounts of non-protein nitrogen (such as elasmobranchs, minced shark), failure to determine protein content independently of the non-protein nitrogen component could introduce error into the measurement.

Moisture Content To determine moisture content, use the AOAC (1984) oven drying method, utilizing an overnight (18 hr) drying period at 100 C. However, the AOAC vacuum oven drying method, which is more rapid, may be substituted. Take samples from the center of fish blocks to avoid freezer-burned areas. Samples should be weighed on an analytical balance at or near room temperature after equilibrating in the appropriate environment (non-desiccating for raw samples, desiccating for dried samples).

Lipid (Fat) Content Lipid content should be measured by the Bligh and Dyer (1959) chloroform-methanol extraction procedure. Acetone extraction procedures are not recommended because sugars are extracted in the acetone-water menstruum and

would be counted as part of the lipid fraction.

Visual Contaminants Use the standard Japanese method for assessing visual contaminants. The technique is as follows: Ten grams of thawed or fresh surimi is weighed (Fig. 1), then compressed to a thickness of 1 millimeter or less between clear glass or plexiglass plates (Fig. 2) (approximately 10 cm x 10 cm). Objects 2 millimeters or more in length or diameter are counted as one; objects less than 2 millimeters in length or diameter are counted as one-half. The sum is reported as the number of visual contaminants per unit area.

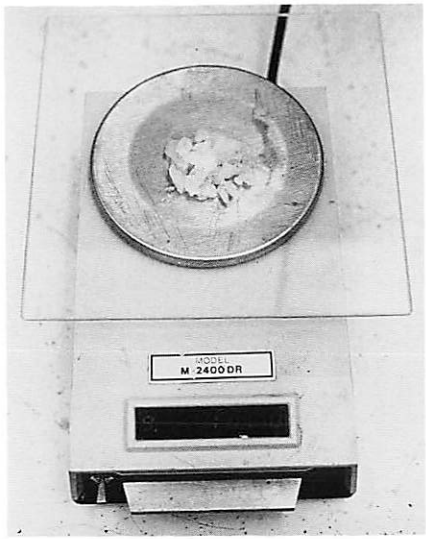

Figure 1. Weighing thawed surimi on glass plate

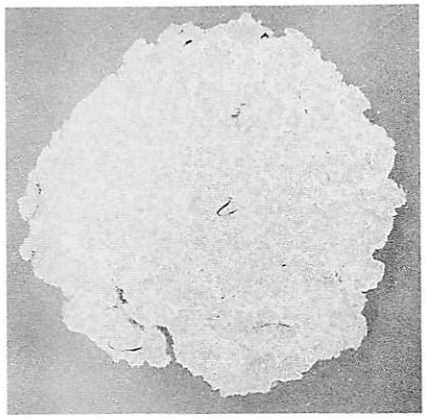

Figure 2. Dark specks of belly lining and other particles are easily visible in the compressed surimi sample

pH Measurement Ten grams of dilute thawed or fresh surimi are added to 190 milliliters of water (Fig. 3) and are blended thoroughly prior to the measurement (Fig. 4). The pH meter used for measurement should be properly calibrated, and the electrode, clean (Fig. 5). Also keep in mind how temperature may affect the measurement. Fresh surimi or minced fish samples may exhibit drift in the reading during measurement. This can be prevented by using a 5mM sodium iodoacetate solution (adjusted to pH 7.0) instead of plain distilled water as the diluting medium.

Rapid Methods Many processors do not have the laboratory

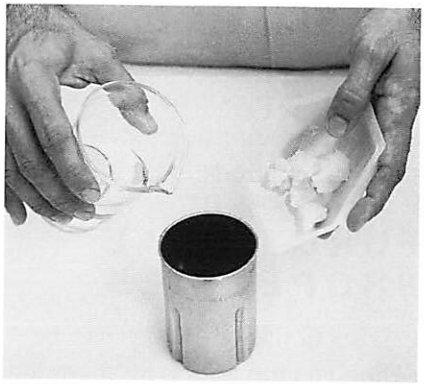

Figure 3. Add saline solution and surimi to blender container

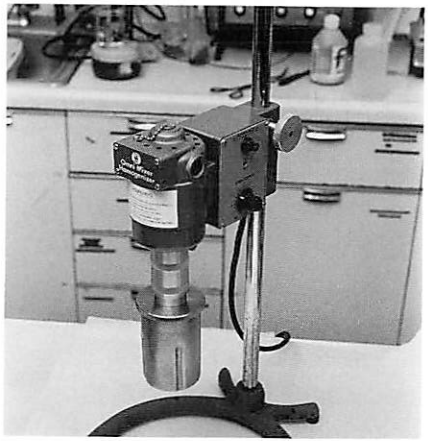

Figure 4. Mixer used to prepare sample

Figure 5. Measurement of slurry pH

facilities to conduct all of the standard compositional tests given above or may prefer to use less laborious and more rapid methods. Any rapid analysis system chosen should compare directly with the standard method for accuracy and precision of results. Rapid protein determination methods include near infrared analysis, titration, colorimetric techniques and calculation by difference from rapid fat and moisture analysis. Rapid moisture techniques include methods based on microwave ovens, heat (infrared) lamps, dielectric/capacitance/resistance measurements, near infrared reflectance analysis, titration and automated conventional ovens. Rapid lipid analysis systems are also offered. Private laboratories can test samples for proximate analysis (fat, protein, moisture, ash) by the standard methods.

FUNCTIONAL PROPERTIES

Functional properties can be defined as the effects an ingredient has on either the organoleptic properties of a food (flavor, odor, texture, appearance, etc.) or on the processing properties of the food (pumpability, extrudability, resistance to tear or breakage, etc.). This definition indicates that a functional property is affected by the quantity of ingredient added to the food and by the manufacturing process.

Functionality measurements are best made by preparing and processing an ingredient using the normal manufacturing process. If the ingredient is a major part of the products it is used in, such as surimi in kamaboko/analog products, it is unnecessary to add most other ingredients (starch, proteins, etc.) to evaluate its functionality. Instead, the surimi may be chopped with salt and sufficient water added to approximate the solids content of the finished product. Then the paste may be cooked by a method similar to that used in manufacturing the product(s).

All measurements of organoleptic and/or physical (i.e., "functional") properties should be

made on a cooked model product. The preparation procedure for the test product is basically identical regardless of the property measured. However, thermal process effects may be important to measure. Surimi is known to sometimes contain protein-degrading enzymes that are heat-activated and that may adversely affect gel-forming ability. Also, the gelling properties are sensitive to the time and temperature of heating and dependent upon species and other factors (i.e., each species may respond optimally to a different processing schedule). Therefore the model test sample should be prepared by the more appropriate of five standard time/temperature schedules. These will enable the processor to accurately estimate the performance of the surimi when subjected to almost any process schedule.

The model product will be representative of most current surimi applications and will predict performance in almost any heated muscle food or protein gel product. Thus an evaluation of the appearance (color), flavor/odor and texture of this model gel gives information that should correlate with the attributes of a commercially produced product containing surimi. Since each manufacturer's process and food formulations vary, establishing the exact correlation between test data and final product attributes is the task of the individual manufacturer.

Preparation of the Model Test Product Use the following equipment and procedure to prepare the model test product:

EQUIPMENT AND MATERIALS

- Stephan Vertical Cutter/Mixer (Laboratory model, UM-5 [Fig. 6] or UM-12 [Fig. 7]) equipped with serrated blades, vacuum pump and fittings. Use of non-vacuum comminution equipment, such as a food processor or a silent cutter, will incorporate air into the

product and distort the measurement.

- Water baths, equipped with temperature control and of sufficient capacity to maintain set temperature when initially loaded with (cold) samples.
- Manual sausage stuffer, preferably crank/piston type, such as Vogt series 9, equipped with appropriate sized horn for tubes being filled.
- 1.9 centimeter (i.d.) stainless steel, polycarbonate or teflon tubes of an appropriate length, equipped with watertight seals and caps. Samples made in these tubes are primarily for the gel-forming evaluation; about 20 centimeters in length is right for this

Figure 6. Vacuum cutter-mixer with 5-liter bowl

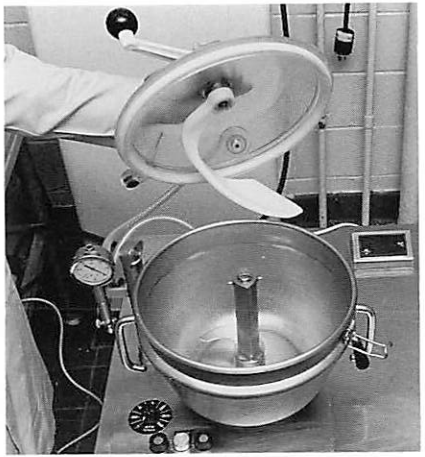

Figure 7. Vacuum cutter-mixer with 12-liter bowl

purpose. Other sized containers may be used as appropriate for flavor and color evaluations. A silicone- or lecithin-containing release agent spray (such as Pam®) is needed to prevent sticking, and immersible trays for holding and transferring the tubes are desirable. Sausage casings may be used for sample preparation if careful attention is paid to obtaining a uniform stuffing pressure and diameter. These parameters must be adjusted and controlled to yield measurements equivalent to the use of rigid tubes.

- Ice bath
- Thermometer
- Balance(s) for accurate weighing of materials
- Laboratory grade sodium chloride (salt)
- Tongs, knives, spatula
- Optional: Vacuum packaging machine with heat sealer, plus appropriate plastic bags

PROCEDURE

1. Remove surimi blocks from freezer and temper at room temperature for 1 hour or in refrigerated tempering room to approximately -5 C (Fig. 8).
2. Cut the surimi blocks into slices or chunks (Fig. 9) and weigh them in a tared pan. Then load directly into the

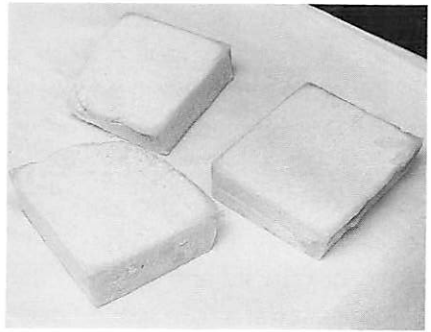

Figure 8. Tempering frozen surimi blocks

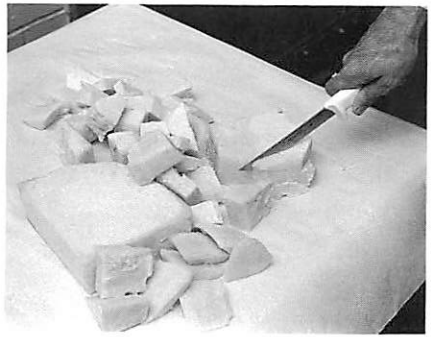

Figure 9. Slicing partially tempered blocks of surimi into chunks

cutter/mixer bowl (Fig. 10) (blade in place prior to loading). To function efficiently, the vertical cutter/mixers require a minimum of 1.2 and 3.0 kilograms for the 5 and 12 liter bowls, respectively.

3. Secure the lid and run the cutter/mixer at a low speed (**no vacuum**) until the material is reduced to particles (Fig. 11). Sprinkle salt (Fig. 12) (2 percent on total batch weight basis) and ice/water (Fig. 13) (sufficient to obtain 78 percent final moisture content on total batch weight basis) evenly over the surimi. To calculate the amounts of salt, surimi and ice/water to add, refer to Figure 14.

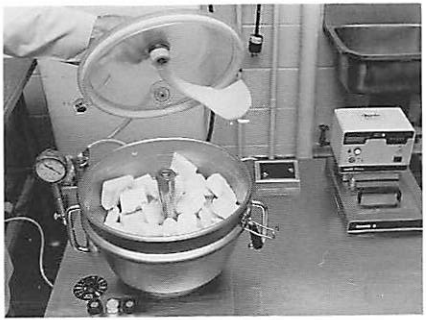

Figure 10. Partially tempered chunks of surimi loaded into cutter-mixer

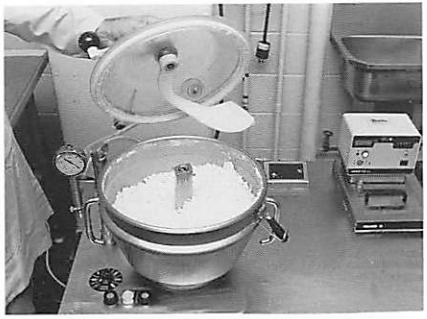

Figure 11. Appearance of surimi following low-speed cutting for a brief time

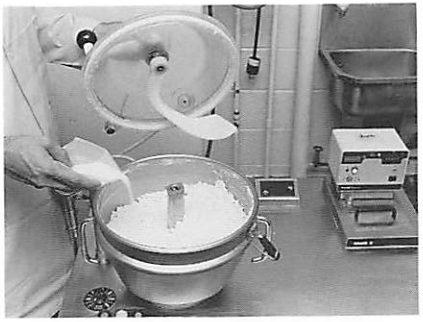

Figure 12. Adding salt to chopped raw surimi

Figure 13. Adding water (or ice) to chopped raw surimi

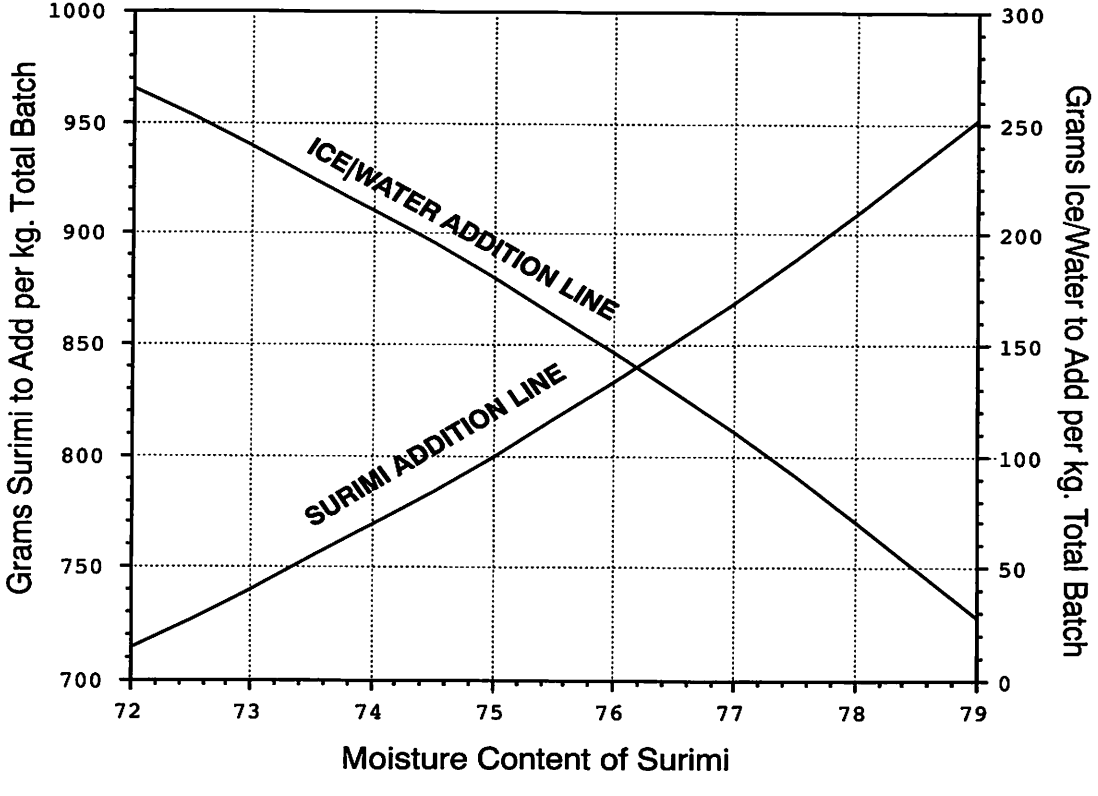

Figure 14. Use for easy determination of salt, ice/water and surimi amounts to be added for preparing test paste of 78 percent moisture content. For each 1000 grams (1kg.) of total surimi paste to be made, determine grams of surimi to be added (left vertical axis) and grams of ice/water to be added (right vertical axis), dependent upon the moisture content of the surimi being used (horizontal axis). To these amounts, always add 20 grams (2 percent) of salt (sodium chloride) for each kilogram of total batch weight.

4. Secure the lid and begin chopping again at low speed with **no** vacuum. Gradually increase the speed to a maximum of 2,000 rpm (adjustable speed models) or high speed on two-speed models. When the mixture becomes a single mass, **turn on the vacuum pump** and obtain a vacuum of approximately 20 to 25 mm Hg. (Fig. 15). During comminution, rotate the stirrer, alternating directions after a few turns to ensure that paste is scraped from the walls and forced down into the blades. Continue in this manner until a temperature of 5 to 7 C is obtained (Fig. 16). Then discontinue chopping.

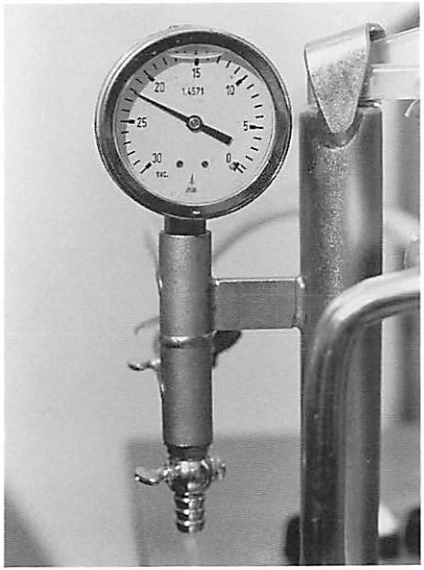

Figure 15. Vacuum gauge should indicate 20 to 25 millimeters of vacuum during subsequent chopping

Figure 16. Temperature should remain well below 10 C

7. Transfer the paste to the sausage stuffer with a minimum of air incorporation. Vacuum packaging is an effective means of doing this. Fold the ends of a vacuum bag outward over itself. This will prevent surimi paste from getting on the inside of the open end of the bag and interfering with a proper seal. Use a long stem spatula to fill the bags full of surimi paste (Fig. 17). When the bag is two-thirds full, flip the ends up and place the bag in an ice bath for transfer and holding. Vacuum package/seal the bag to eliminate large air pockets caused by transfer to the bag (Figs. 18 and 19). Prior to loading into

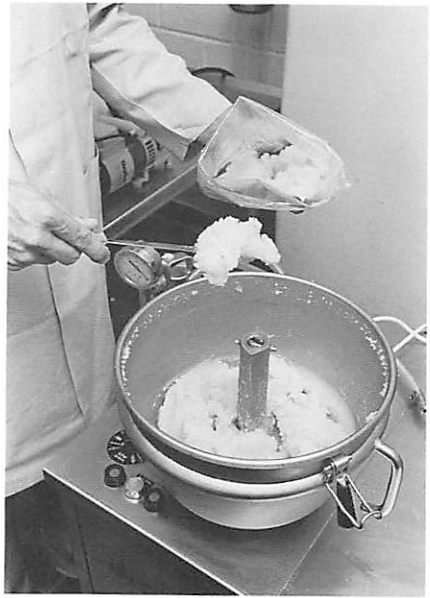

Figure 17. Loading plastic bag with chopped surimi paste for air removal

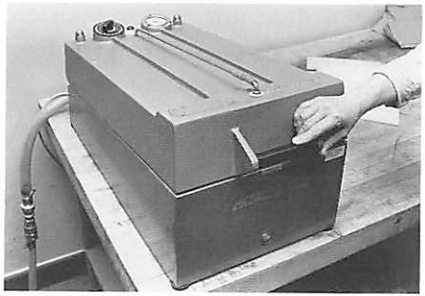

Figure 18. Remove large air pockets in the bag with vacuum packaging machine

Figure 19. Open and reseal bag to achieve good air removal

the stuffer, massage the paste away from one end of the bag and cut the bag open (Fig. 20). Place the bag at the bottom of the sausage stuffer with the open end nestled firmly in the exit port of the stuffer (Fig. 21). Do not allow surimi to remain unrefrigerated for more than a few minutes prior to stuffing.

8. Spray tubes with release agent prior to filling (Fig. 22). Extrude the paste uniformly and without air pockets into tubes with the stuffer (Figs. 23 and

Figure 20. Cut bag open

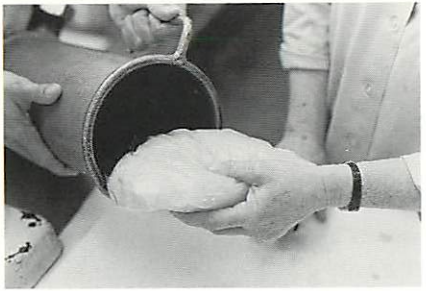

Figure 21. Load into manual stuffer

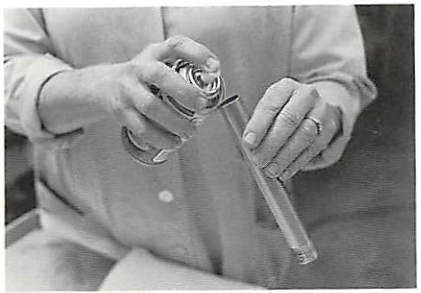

Figure 22. Spray stainless steel tubes with lecithin release agent

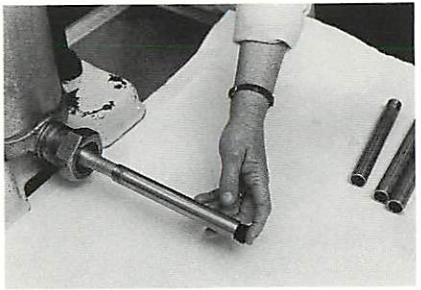

Figure 23. Stuff tubes by inserting over stuffing horn

24). Seal both ends (Figs. 25 and 26), and place in an ice bath until ready to heat process.

9. Immerse filled tubes in water bath(s) (Fig. 27) previously equilibrated to the proper temperature. The proper time-temperature relationships for thermal processing, as determined from heat-penetration curves, are:

Low temperature setting ability: 0 to 4 C for 12 to 18 hours, followed by 90 C for 15 minutes.

Median temperature setting ability: 25 C for 2 hours, followed by 90 C for 15 minutes.

High temperature setting ability: 40 C for 30 minutes,

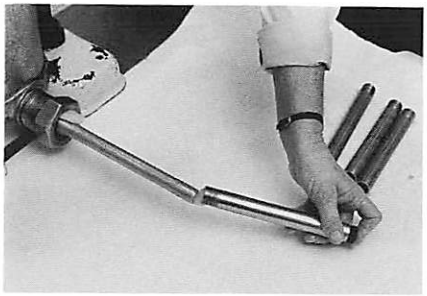

Figure 24. Pull away as the material is extruded

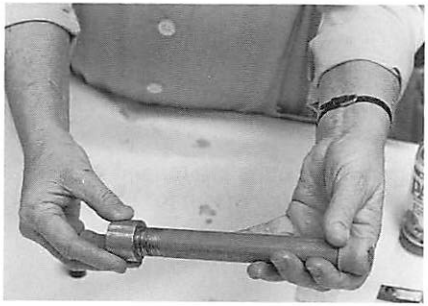

Figure 25. For stainless steel tubes, a rubber stopper is placed on one end and the other sealed with a screw cap

Figure 26. Clamp the rubber stopper to prevent popping off during cooking as the paste expands (if tubes are to be fully immersed in water)

followed by 90 C for 15 minutes.

Detection of protease activity: 60 C for 30 minutes, followed by 90 C for 15 minutes.

Rapid cooking effect: 90 C for 15 minutes.

Color and flavor determinations are made on samples cooked only at 90 C (rapid cooking effect). As mentioned earlier, these samples may be cooked in containers convenient for the sample shape and size needed for measurement (described later).

10. After heat processing, quickly transfer tubes to an ice water bath (Fig. 28) and allow to equilibrate in temperature (0 C). Then remove gels from

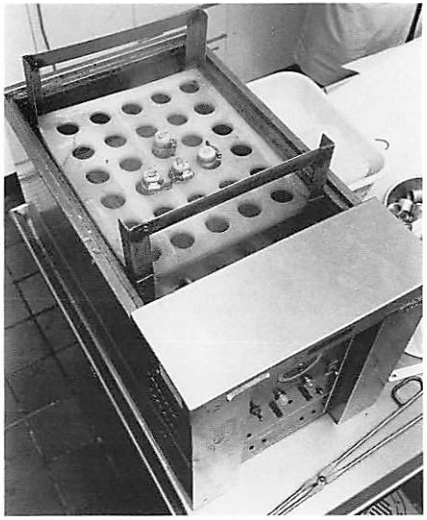

Figure 27. Tubes are loaded into a rack in the water bath for heat processing

Figure 28. Immediately after heating, cool tubes in ice/water mixture

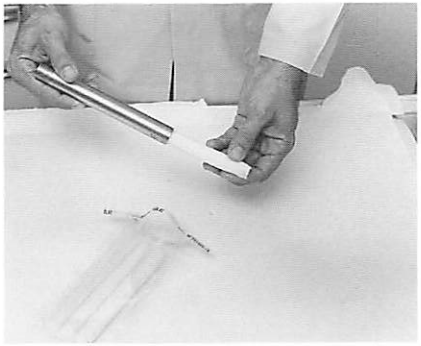

Figure 29. Remove cooked gel cylinders (a teflon plunger may be needed) and seal in plastic bags

tubes with a plunger (Fig. 29), and seal in plastic bags. Keep samples refrigerated until testing. Samples should be tested within 24 to 48 hours.

Determination of Gel-Forming Properties To determine the gel-forming ability of surimi, measure the fundamental rheological properties of the model product when strained (deformed by tension, compression or shear) to failure (breakage). For surimi gels (which are very cohesive), a torsional (twisting) deformation is the only geometry of measurement that will enable a precise calculation. The test is conducted on milled samples in a specified testing fixture.

EQUIPMENT NEEDED

- Torsion gelometer fixture‡
- Millivolt strip-chart recorder or data-logging computer‡
- Specimen milling machine‡
- Styrene sample mounting discs‡
- Mounting jig for attaching discs to sample‡
- Sample length cutting jig‡
- Cyanoacrylate glue
- Calipers (metric)

‡ Check supplier list (Appendix 3) for names and locations of companies that can provide the above equipment.

PROCEDURE

1. Allow refrigerated samples to reach room temperature (near 25 C) before testing. In cold environments, it is recommended that samples be held in a closed container in a water or sand bath at 25 C prior to testing. Cut samples to a length

of 28.7 millimeters with a guillotine jig (Fig. 30).

2. Glue sample to styrene mounting discs with cyanoacrylate glue. Use the mounting jig to ensure alignment of the notches on the styrene discs. Apply glue to each disc before contact with the sample (Fig. 31). Use glue sparingly, spreading over the entire contact area. Be careful to place samples in center of mounting discs (Figs. 32, 33 and 34).
3. Mount the sample in the milling machine by aligning the pins in the notches of the sty-

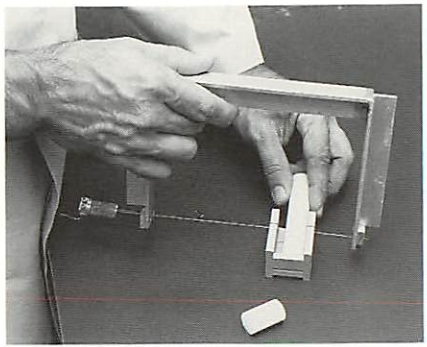

Figure 30. Gel cylinders are cut to size

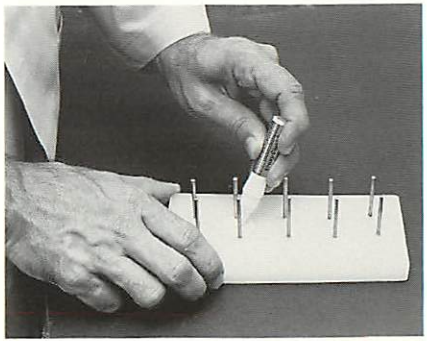

Figure 31. Cyanoacrylate glue is applied to a mounting disk

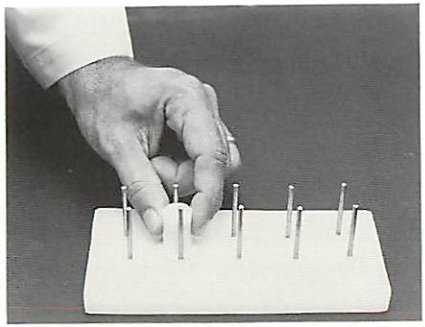

Figure 32. The gel cylinder is placed in its center

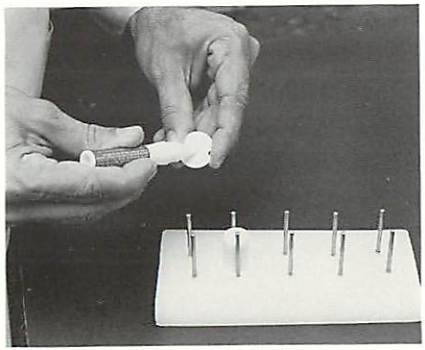

Figure 33. Glue is applied to a second disk

rene end discs (Fig. 35). Rotate the sample-holding section into position to slowly advance the sample into the cutting wheel by turning the crank (Fig. 36). The 6-inch diameter cutter rotates at 3,450 rpm. The rotational rate of the specimen should be approximately 20 rpm. The minimum diameter of the milled portion of the sample should be exactly 1-centimeter. Occasionally check for accuracy with calipers.

4. Mount the milled sample in the torsion fixture by aligning the

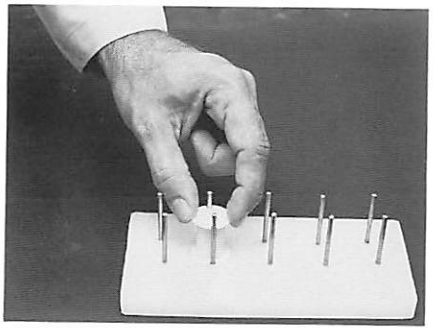

Figure 34. The disk is applied to the top of the sample

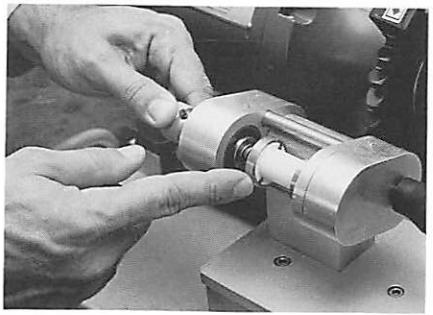

Figure 35. The mounted sample is loaded into the milling device

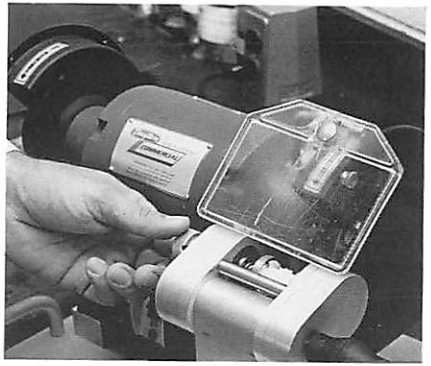

Figure. 36. The sample is milled by moving it into the milling wheel

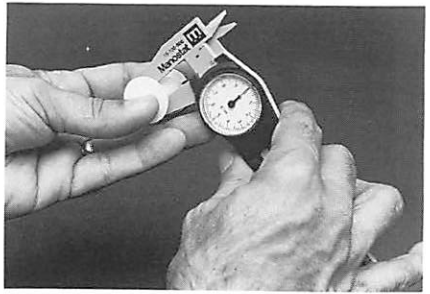

Figure 37. The minimum diameter of the milled sample is periodically checked with a caliper

bottom pins into two notches at the end of the styrene disc. Then turn the knurled knob of the fixture to engage the top pins in the top disc (Fig. 38). The sample should be held firm and vertical but not compressed in the fixture.

5. Zero the strip chart pen or data logger if necessary. With the strip chart running (Fig. 39) (20 cm/min), turn on the gelometer motor (Fig. 40) (2.5

Figure 38. The milled sample is mounted into the torsion device

Figure 39. The torsion gelometer device with data feed to a strip chart or small computer

rpm setting). Allow it to rotate until the sample breaks (Fig. 41) (the chart pen will deviate sharply from an upward movement back toward the baseline). Then turn the viscometer and strip chart off.

6. From the strip chart recording (Fig. 42) (or logged data if a data logging computer is used), measure the chart travel distance (angular deformation) and torque (digital viscometer reading) at breakage. Calculate stress and true strain at sample

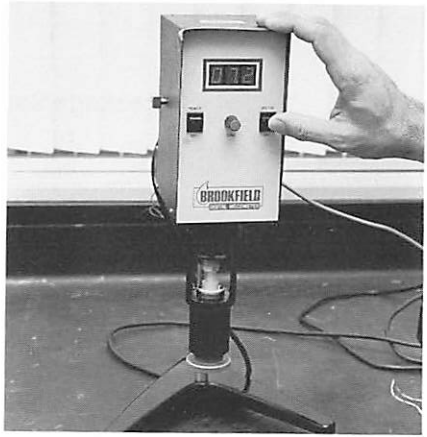

Figure 40. The test is initiated by turning on the motor; torque is indicated by the digital meter

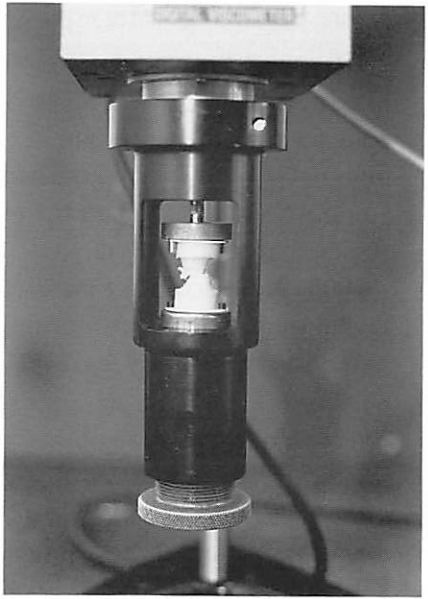

Figure 41. The sample is twisted to the point of failure (breakage)

failure by the following equations:

Shear Stress = τ =1581 x (viscometer max digital torque units)

Strain = γ = 0.150 x (chart travel distance, mm / chart vel, s) - 0.00847 x (viscometer max digital torque units)

True Shear Strain = $\ln [1+(\gamma^2/2)+\gamma(1+\gamma^2/4)^{0.5}]$

Program these computations onto a calculator or computer spreadsheet for ease of use. A computer can be used to automate the twisting and to report data directly as fracture stress and fracture true strain. Report shear stress and true shear strain.

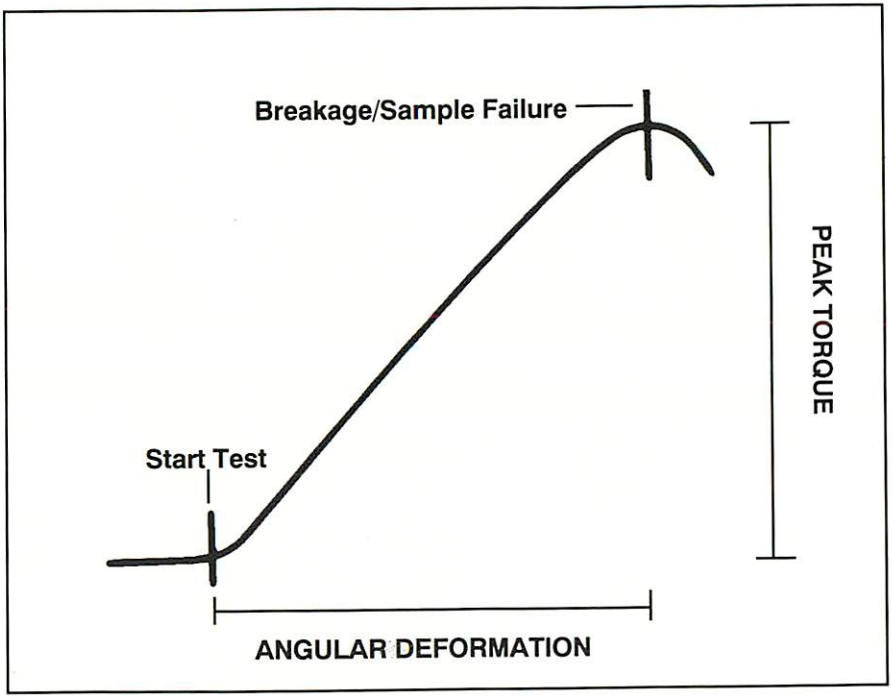

Figure 42. Torque and angular deformation at failure are easily determined from the strip chart recording

INTERPRETATION OF SHEAR STRESS, TRUE SHEAR STRAIN MEASUREMENTS

These two primary and independently measured mechanical properties indicate the strength (stress) and cohesiveness (true strain) of a surimi gel. An X/Y plot of these two measurements provides a textural "map" of the gel-forming properties of surimi (Fig.43).

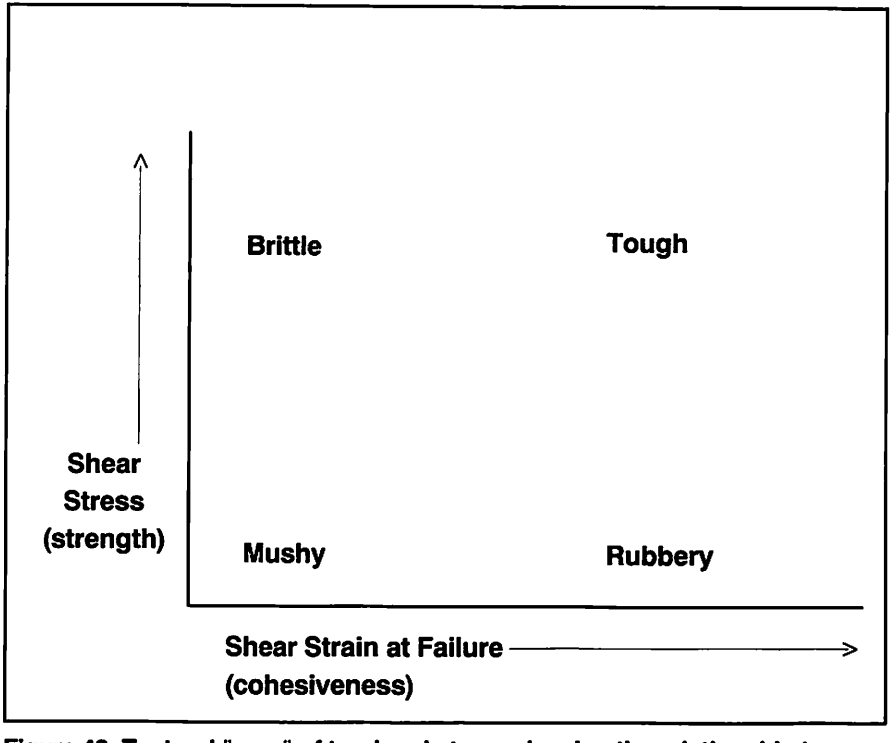

Figure 43. Textural "map" of torsional stress showing the relationship to sensory terms describing textures of surimi gels

Experience has shown that moisture content and heating temperatures primarily affect vertical movement (stress) on this plot. Horizontal movement (true strain) is more affected by the freshness of fish used to make the surimi, the degree of washing and the temperature control exercised during its manufacture. Specifications for surimi can be depicted as a square or circular "window" on such a plot to determine if incoming or outgoing product conforms to specifications.

Determination of Color It is best to measure the color of surimi instrumentally rather than by visual comparison with photographs. Any colorimeter or spectrocolorimeter capable of accurately measuring color in the CIE LAB scale is suitable. In this scale L* denotes lightness on a 0 to 100 scale from black to white; a*, (+) red or (-) green; and b*, (+) yellow or (-) blue (Fig. 44).

Surimi will have L* values well above 50 and positive but low values of a* and b*. To increase the accuracy and reproducibility of measurements among instruments, a calibrated color tile approximating the color of high quality pollock surimi is used in a Hitch Standardization procedure. This "Hitching Post" technique will reduce differences in subsequent color readings between different instruments for the pur

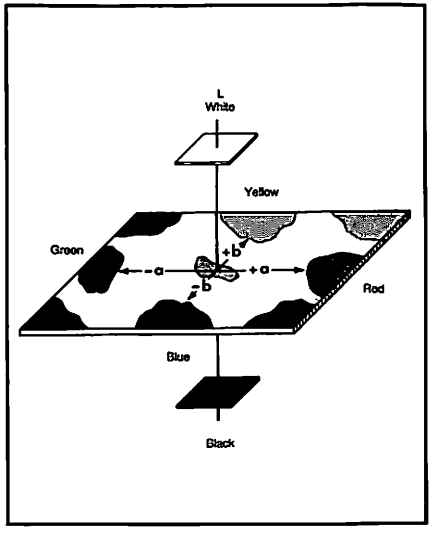

Figure 44. The L*, a*, b* color space

poses of measuring surimi. The surimi Hitch Tile is available from the National Fisheries Institute through Hunter Associates Laboratories (Reston, Va.)

The standard technique for measuring the color of surimi is as follows.

1. Prepare a cooked gel sample (use the 90 C cooking technique described earlier) that is at least 5 centimeters in thickness and at least twice as large in diameter as the size of the measuring port on the instrument.
2. Standardize the instrument as per the manufacturer's instructions. Then follow the manufacturer's instructions for Hitch Standardization. This normally entails first keying in the calibrated values printed on the back of the Hitch Tile in the same scale, observer angle and illuminant (Fig. 45). Then read the tile as you would any sample (Fig. 46)

   Use optically clear glass to protect the instrument when measuring the surimi. If this is done, the instrument should also be standardized through the glass.
3. The sample is then measured

Figure 45. Enter the color coordinates of the Hitch tile into the memory of the colorimeter

Figure 46. Reading the Hitch Tile

with the 2 degree observer and illuminant D65 (Fig. 47). The color values obtained are recorded with the illuminant, observer angle and instrument type. Readings from three duplicate samples should be averaged.

A larger viewing port is more desirable for better surface averaging per reading, particularly when the surimi contains significant numbers of visual contaminants ("specks").

A "whiteness" index helpful for overall color evaluation of surimi is determined as: 100 minus the distance in color space from the point of maximum whiteness to the point that represents the sample color. This is calculated as: whiteness = $100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{0.5}$

Many other formulas for whiteness calculations have been published (ASTM, 1987; Wyszecki and Stiles, 1982). When a whiteness measurement is specified, the method of calculation should also be stipulated. However, when specifying the color of surimi, all three primary values, i.e. L^*, a^*, b^*, should be given regardless of whether a whiteness value is calculated. The color

Figure 47. Measurement of the sample color

measuring instrument should also be specified (ASTM, 1987).

Determination of Flavor and Odor Evaluations of flavor and odor are subjective and can not be made by objective, quantitative methods. For purposes of commerce, buyers and sellers must define their own set of flavor/odor criteria. For research purposes, conduct flavor/odor profiling of samples using trained panels to measure the predominant flavor/odor notes and their intensities. Samples used for flavor/odor analysis should be prepared by cooking to a minimum internal temperature of 85 C for 25 minutes. Distinquish between those flavor and odor characteristics common to the species or due to the normal additives versus those that are indicative of spoilage or poor handling.

Traditional Japanese Testing Methods

The Japanese originally developed the surimi industry and a set of empirical methods for measuring surimi functional properties. However, the methods vary from company to company and technologist to technologist. This can lead to confusion in interpreting results. A thorough comparison of the present U.S. standard methods was made with the published Japanese methods in 1985 (Lanier et al., 1985). It highlighted significant errors in measurement that can be expected with the Japanese methods. Nonetheless, the current domination of the surimi industry by the Japanese will doubtless see the persistence of their methods in our industry for some time to come.

Other techniques have been proposed and used by researchers for routine quality control that are rapid and that yield measurements which have limited usefulness. In manufacturing, it may be useful to employ measurement techniques that are more rapid than the standardized methods even when accuracy or precision may be compromised. Although such methods may have utility for in-house requirements, they do not always accurately or precisely predict the true gel-forming potential of surimi. Thus they should not be used for writing specifications in general commerce.

In 1980, the Tokai Regional Fisheries Laboratory developed more uniform grading procedures for surimi produced by Japanese land-based plants and factory ships. Cooperating in this effort

were the Deep Sea Trawlers Association, the Hokkaido Surimi Association, the Kamaboko Manufacturers Association and the All-Japan Frozen Fish Meat Association. These Japanese standard test procedures were summarized by Shimizu (1981) and Lee (1984). *They are reproduced in Appendix 1.* The following is a commentary on these methods. It is divided into tests performed on raw surimi and on a cooked gel (kamaboko) prototype.

RAW MATERIAL TESTS

Tests conducted on raw (uncooked) surimi samples for pH, color, water holding (drip under pressure) and viscosity are indicators of functional properties that are only fully expressed when the paste is heat treated to form a gel. For example, the pH and water-holding properties of raw surimi are related to the water-holding and gel-forming properties of cooked gels. However, they do not necessarily accurately predict the latter.

Color (whiteness) is affected by protein coagulation in heated surimi samples and by the entrainment of air bubbles in either the heated or raw sample. Both lead to increased light scattering and a whiter color.

Viscosity is a useful indicator of protein quality because it decreases dramatically as the protein denatures. However, cases have been documented in which viscosity of the raw surimi paste did not correlate with cooked gel texture among varying samples (Kim et al., 1986).

The test for viscosity of a salted, *diluted* surimi sample (Appendix 1: A.1.d.) is similar to that documented by Borderias et al. (1985). It employs measurement of the viscosity of a salt solution

of surimi using a Brookfield viscometer (Fig. 48). It is useful as a rapid way to estimate the quality of the protein in frozen fish samples.

The viscosity of a salted, *undiluted* surimi paste is an important factor in its machinability during manufacturing. The above test, being conducted on a dilute extract of the paste, is not helpful. A piston-type extrusion viscometer (Fig. 49), mounted in an Instron Universal Testing Machine, is best used for this measurement. The viscosity is calculated by measuring the force required to extrude the paste through a narrow capillary at any particular rate (crosshead/piston

FIgure 48. Measurement of the apparent viscosity of dilute solutions of surimi to estimate quality of the surimi

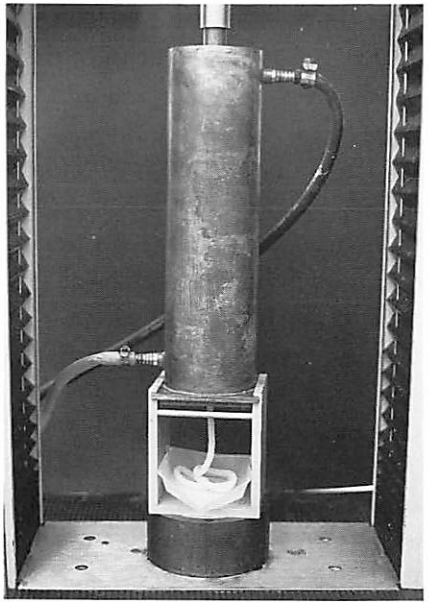

Figure 49. A piston-type extrusion viscometer fixture mounted to an Instron Universal Testing Machine

speed). Two different lengths of capillary (Fig. 50A) are used sequentially during the measurement to allow subtraction of the frictional forces; each is inserted into the device prior to a test (Fig. 50B). The surimi paste is loaded into the viscometer with a sausage stuffer fitted with a large diameter horn. This measurement is described in more detail by Kim et al. (1986).

Because these tests on the raw surimi are indirect measurements of the properties important to the food processor, direct measurements on a fully cooked gel are preferable and should be used to assess the functionality of surimi. Otherwise, it is possible that a surimi sample may display undesirable traits in indirect tests yet perform well in the product application (and vice versa).

The specified tests for moisture content, pH and impurities are straightforward and represent a common-sense approach to these simple measurements. As mentioned, rapid tests for moisture content are now available. They are finding acceptance in the Alaskan surimi industry.

COOKED GEL (KAMABOKO) TESTS

Preparation of Test Samples

The type of comminuting machinery is not specified in the Japanese methods (Appendix 1:

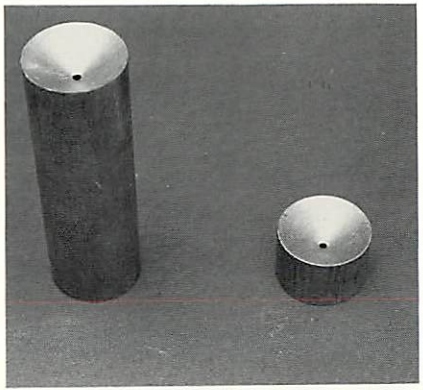

Figure 50A. Long and short capillary tubes for viscosity determination

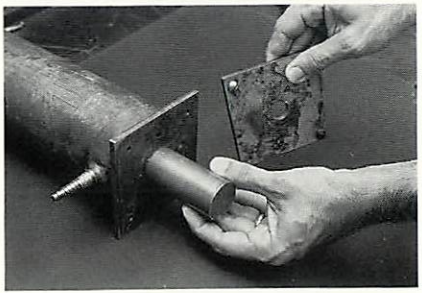

Figure 50B. Inserting a capillary tube into the viscometer fixture

B.1.a). Nor is a precise time or final temperature for chopping/grinding specified. This is a critical step in preparing the samples. The degree and time of comminution and the amount of air incorporation are factors that can affect the textural properties of the finished product.

The option of including potato starch (at one of two levels) is given. Starch inclusion will increase the punch force measurement to a degree dependent upon the quality of starch and the amount of water it imbibes during cooking. The punch force is also affected by the moisture content of the sample, which is not standardized by this protocol.

The chopped paste is stuffed into shirred (folded) casings (Appendix 1: B.1.b) (Fig. 51). This procedure specifies a 48-millimeter diameter casing, but the industry commonly uses a 30-millimeter casing (Lee, 1984) shown in the figure. [The stuffing pressure and technique also affect the measurement (Lanier et al., 1980; Lanier et al., 1985; Babbitt and Reppond, 1988) and can vary more when casings, rather than rigid tubes, are stuffed.]

The stuffed casing is placed in a hot (90 C) water bath (Appendix 1: B.1.c) and kept fully submerged by weighting the casings

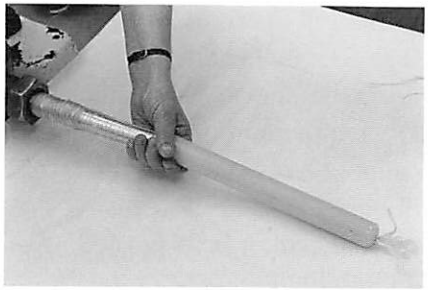

Figure 51. Extrusion of the surimi paste into casings

or placing them under a frame (Fig. 52). By heating the samples using the direct cook method, the low temperature setting ability cannot be measured or the levels of heat-activated proteases present cannot be estimated. Although the Japanese protocol does allow for a suwari (setting) measurement, the procedure is not specified.

Gel Texture Measurement Techniques Either an Okada gelometer or an electronic rheometer is specified (Appendix 1: B.2.a). The Okada gelometer (Suzuki, 1981) is an early device that drives the plunger with constantly increasing force (variable speed) as water is poured into the plunger cup. Reported speeds for the plunger are much slower than those of the modern rheometer, which drives the plunger at a constant speed (variable rate of force increase). Although relative differences between samples will remain about the same regardless of plunger speed, absolute values will not. Faster speeds yield higher force readings at fracture. Therefore, the speed of the plunger should be specified and constant. The Rheo Food Checker, a common instrument used for this test, has

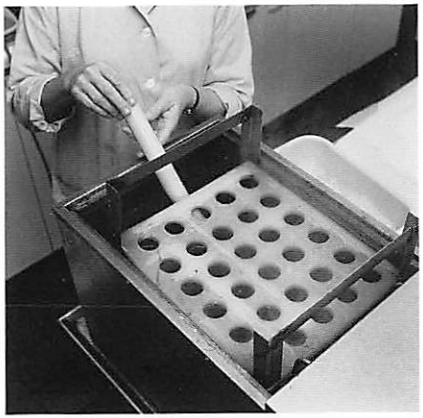

Figure 52. Inserting stuffed casings under a rack ensures full submersion during heating

a probe speed of 60 millimeters/minute.

The cooled samples are peeled to remove the casing (Fig. 53) and cut to height (similar to the method depicted in Fig. 30) prior to testing. The cut samples are centered under the rheometer's plunger (5 mm diameter spherical head), and the test begun (Fig. 54). The test curve will resemble that generated by torsion testing (Fig. 42): a nearly linear response of force versus deformation to the point of failure. However, the shape changes that the sample undergoes during punch testing on this rheometer preclude an accurate calculation of the stress and strain at the point of breakage (Hamann and

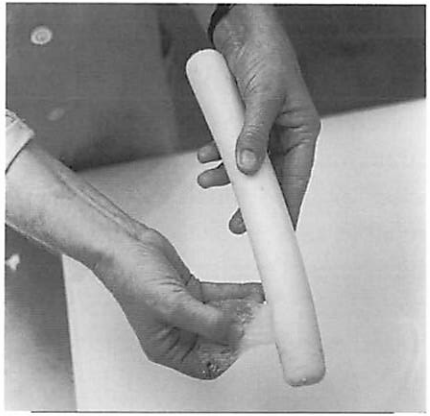

Figure 53. Peel casings before cutting samples from cooled gel

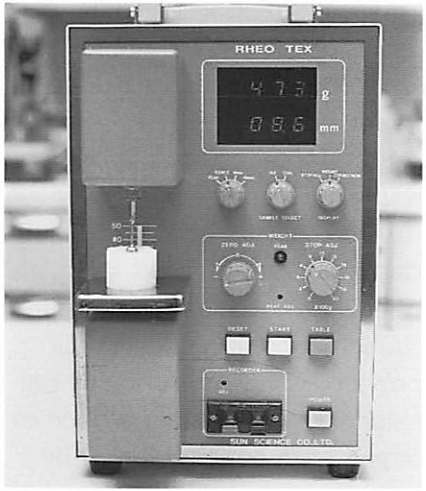

Figure 54. Electronic punch test machine

Lanier, 1986). Consequently, the results of this test will not necessarily correlate with the true stress and strain.

Only within certain limitations is it possible to use punch test data to estimate the U.S. standardized test scores of stress and strain. Extensive experimentation (Lanier, unpublished data) has provided a means of roughly estimating the stress/strain properties of gels from punch test data by the following equations.

Stress = 4.9746 + 0.1135 (Punch Force, g) R= 0.97

Strain (true) = 1.4365 + 0.082 (Punch Deformation, mm) R = 0.69

The correlation coefficient (R) for the stress value prediction is better (R = 1.0 indicates perfect correlation) than that for the strain value prediction. This indicates that the punch test is least reliable as a predictor of the cohesiveness (true strain) of a surimi gel. These equations were found to be valid only under limited conditions:

1. When the surimi being tested is high in moisture content and contains high quality protein, the punch test will likely yield erroneous measurements. It is best to conduct measurements at 78 percent moisture content. But the equations should be correct for gel moisture contents in the 74 to 80 percent range.
2. The equations should be used only with samples of gels that pass the Japanese double-fold test (i.e., a 3-mm slice of gel folded twice without cracking). This would correspond to a true strain value of at least 1.9.
3. Punch test results must be obtained at the same crosshead speed (60 mm/min) and using the same type probe (5-mm spherical end) as the Rheo Food Checker. Any departure from the procedure outlined will result in substantial deviations of the readings.

For the purposes of trade and contracts, the producers and users of surimi should conduct the standard torsion test even when routine use of the punch test in-house is deemed desirable. The punch test overestimates the gelling ability of higher quality surimi protein relative to measurements made by torsion (Hamann and Lanier, 1986). Therefore, punch measurements are not useful for predicting the gelling properties of surimi blends (e.g., in least cost formulation).

As has been explained, the texture of surimi gels is at least a two dimensional attribute (strength, cohesiveness). The Japanese testing procedure (Appendix 1: B.2.a.) calls for calculation of "jelly strength" as the product of these two variables. This obscures the contribution of each to overall gel texture. For example, a soft but cohesive gel would yield the same score for jelly strength as a firm yet brittle sample. Also, since the punch force value is inversely related to the moisture content, one common ploy to increase the "jelly strength" of poor quality surimi is to decrease its moisture content. This does not improve the gelling properties of the surimi but merely covers up the poor quality.

The sensory test described for textural gel analysis (Appendix 1: B.2.d.) is more subjective than instrumental methods and less precise due to variability in scoring among judges. Like the jelly strength calculation, it also is one dimensional, ignoring differences due mainly to strength or cohesiveness alone.

The folding test (Appendix 1: B.2.e.) is conducted by folding a 3-millimeter thick slice of gel slowly in half and then in half

again (Fig. 55A, B, C) while examining it for signs of structural failure (cracks). The minimum amount of folding required to produce a crack in the gel determines the score for this test. Careful comparison of fold tests and torsional measurements made on identical samples has indicated that the fold test can distinguish some differences in gel cohesiveness (true strain) up to a value of 1.9. Gels exhibiting strains at failure higher than this (and good quality surimi commonly ranges 2.0 to 3.0 in true strain) are indistinguishable by the fold test. Thus the fold test is suitable for mainly separating high quality from low quality surimi. It is not sensitive to differ-

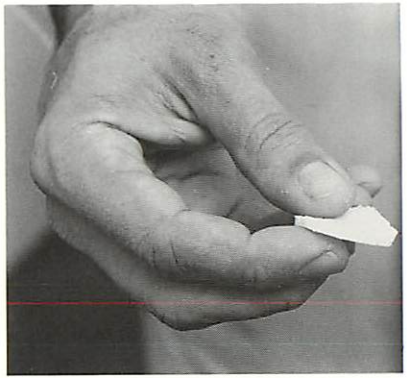

Figure 55A. A 3-millimeter slice of surimi gel

Figure 55B. Surimi gel folded once lengthwise

Figure 55C. Surimi folded in half again with no cracking

ences in quality of surimi that exhibit good to excellent gelling ability.

Color Measurement Techniques The color measurements specified by the Japanese testing protocol (Appendix 1: B.2. b,c.) do not specify the thickness or diameter of samples. These factors can affect the measurement. Whiteness is specified by the CIE Z measurement; brightness, by the L measurement of the Hunter system. These are one-dimensional measurements that ignore the contribution of other components (X and Y in CIE, a and b in the Hunter system) that may affect the visual perception of the color.

Why the terms whiteness and brightness were applied to these measured values is unclear. In the U.S. pulp-and-paper industry, as well as in the textile industry, additives are often used to increase whiteness. These additives absorb energy from the ultraviolet (non-visible) region of the spectrum and re-emit light (fluorescing) in the blue region. The human eye perceives this (or any) added energy in the blue region as brightness. Although surimi is not fluorescent, its brightness can be measured in the blue region. This can be accomplished by using the Z tristimulus value of the CIE system.

In measuring brightness, the above industries generally use an empirical modification of the Z value called Z percent (Z%), which is calculated as 1.18103 times the Z value. The American Society of Testing Materials (ASTM, 1987) has a standard for whiteness that is calculated as 4(Z%) - 3Y. This whiteness index is applicable to any leaching process. It may also be applicable to surimi. The CIE Y value is directly correlated to the Hunter L value used for the "brightness" measurement in the Japanese surimi testing protocol (each denotes *lightness* of color in their respective systems).

Japanese Systems of Establishing Surimi Grades It is apparent from a review of published materials that grading criteria are not uniform among Japanese manufacturers. A report issued by Ashenden Pacific Marketing (1983) noted separate standards for land-produced surimi published by the All-Japan Frozen Fish Meat Association (AJFFMA) and the Hokkaido Surimi Association (HSA). These separated pollock surimi into six and four grades, respectively. The former encompassed moisture contents ranging from 79 to 82 percent, but the latter represented a moisture content range from 75 to 78 percent. The reason for the discrepancy in moisture contents may lie in the different amounts of cryoprotectants added under these two different grading methods (5 percent for the AJFFMA scale and 10 percent for the HSA scale). Also, the HSA scale is given for salted surimi.

Surimi grading appears to be essentially a two-step process in Japan. The surimi is first graded by moisture content, appearance and perhaps freshness of the fish. This determines the amounts of starch to be added to conduct the evaluation of the gel-forming properties. According to the AJFFMA and HSA grading protocols, the surimi must always obtain an "AA" (fold twice without breaking) score on the fold test to be worthy of a grade.

Despite the listing of six grades by the AJFFMA, only three grades of land-produced (in Japan) surimi are traded. These are special class, first class and second class. The Ashenden Pacific report said second class product represented nearly 99 percent of the total land-based production.

This report also stated that formal grades for at-sea produced surimi did not exist because two companies monopolize the production of this product. It was stated that up to six grades existed. These "represented the

number of sequences through which the product is processed before reaching acceptable standards of fineness."

Suzuki (1981) lists four grades of salted and unsalted Alaska pollock surimi. There is some confusion in the labeling of the figure she gives as to whether these grades are for land-produced or at-sea produced surimi. The moisture range of the unsalted grades is 79 to 82.5 percent, calling for the addition of starch at the 0, 3, 5 or 10 percent level depending upon the moisture content. The moisture levels of the salted grades are identical to those of the Ashenden report (1983), while those for the unsalted grades (Suzuki,1981) are very similar. Oddly, Shimizu (1981) gives a similar grading scheme for unsalted surimi (requiring 0 to 10 percent starch addition), except for the moisture content ranges from 77 to 80 percent. He references this grading procedure as that adopted by the AJFFMA in 1978. Sonu (1980) also presents this same information. Miyauchi et al. (1973) presented grading criteria for unsalted Alaska pollock surimi supposedly established by the HSA in 1965. These are similar, but not identical to, those given by Suzuki (1981).

Criteria for assigning grades for at-sea and land-produced surimi were presented in a 1984 Surimi Workshop in (Anonymous, 1984) Seattle, Wash. (Appendix 2). The grading scale for land-produced surimi was similar to that presented by Shimizu (1981). It specified that 5 percent cryoprotectants be added, but Shimizu stipulated 8 percent additives.

The at-sea produced product is divided into six grades according to this report. The moisture content is regulated tightly at a low level in all grades. Gel strength testing is conducted with and without starch (3 percent regardless of moisture content). According to this scheme, grade

determination is based on the lowest score for any one criteria.

From this discussion, it is apparent that grade designations such as FA, SA, A, B, C can have variable meaning depending upon the supplier. Indeed suppliers may discount desirable qualities that a buyer wants. Buyers should examine a test lot for the particular properties desired (i.e., buy on specifications) rather than simply designate a quality grade based upon the present (confusing) criteria.

Conclusions

The development of U.S. standard methods for surimi quality determination signals a departure from a nonstandardized, empirical approach to surimi quality measurement and specification. The methods adopted by the subcommittee yield measurements that are fundamental and better correlated with sensory experience. For example, stress and strain measurements correlate with sensory texture evaluation of surimi gels better than punch or compression measurements (Lanier et al., 1985). They also provide a more accurate and independent measurement of these two parameters of the gel. The enhanced accuracy eliminates skewed comparisons of samples varying in magnitude of either parameter and permits accurate prediction of the gel properties of surimi blends (least cost formulation). Separation of the parameters (i.e., stress and strain are measured independently, unlike with the punch test) allows differentiation between inherent functionality of protein and simple moisture content or starch filler effects (Hamann and Lanier, 1986). Likewise, the CIE LAB system of color measurement combines the fundamental soundness of the CIE physics-based system of color measurement with the more sensory-based Hunter color system.

These methods should serve as a model for international standardization of surimi testing methods, as they offer advantages for both commercial and research applications.

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Appendix 1. Japan Frozen Surimi Quality Testing Standards

Frozen Surimi Quality Testing Standards were established in 1980 as a result of several study meetings held by interested companies, associations and the Tokai regional fisheries laboratory under the leadership of the Fisheries Agency to decide upon the required standards for testing surimi quality.

Test	Testing Method	Comments
A. Raw Material Tests		These tests evaluate the quality of surimi in its existing state
1. Required Tests		All required test items must be implemented.
a. Moisture	Thawing of the frozen surimi block or portions of a block should be done in the polyethylene bag to prevent moisture evaporation.	Surimi should not be removed from the polyethylene bags for thawing.

Test	Testing Method	Comments
a. Moisture (cont.)	Remove a test sample from the above partially thawed surimi block.	Error between sections of the block can be substantial.
	When using a drying oven, the test samples should be scaled in a polyethylene bag or bottle. After the sample temperature reaches 0 C or above, remove between 5 to 10 grams in a weighing bottle, then dry at 100 to 105 C until reaching a constant weight.	Placing frozen surimi into a weighing bottle can be a cause of error because of the dew condensation of the outer surface of the container.
	When using infrared moisture measurements, 5 to 10 grams of the surimi that has been thawed by the method described above may be cut into thin slices and placed immediately in the sample dish for drying.	
	When using the drying oven or	

Test	Testing Method	Comments
a. Moisture (cont.)	infrared moisture measurement, three or more samples should be used, with the average value expressed in percentages. Moisture (%) = $\frac{\text{Weight before drying(g)} - \text{Weight after drying}}{\text{Weight before drying (g)}} \times 100$	
b. pH	Add 45 milliliters of distilled water to 5 grams of the sample. Place in a blender to create a homogeneous mix, then measure with a pH meter. Measurement should be conducted on two or more samples and expressed in average values.	Add water to surimi at a ratio of nine to one. A mortar may also be used for blending the samples When no pH meter is available, BTB pH indicator paper may be used.

Test	Testing Method	Comments
c. Detecting impurities	Ten grams thawed surimi is compressed to 1-millimeter thickness or less. Count objects 2 millimeters or more in diameter as one and objects under 2 millimeters in diameter as one-half.	Impurities for purposes of this item are defined as black membranes, small bones, etc. other than fish meat.

Score	No. of Impurities
10	0
9	1-2
8	3-4
7	5-7
6	8-11
5	12-15
4	16-19
3	20-25
2	26-30
1	over 31

Test	Testing Method	Comments
2. Optional tests		Stable measurement values have yet to be attained for optional tests at the current time.
a. Hunter	Pack appropriate amount of thawed surimi into a measuring glass container leaving no open spaces, then immediately measure with a color-difference meter (whiteness tester), using the CIE (Commission Internationale de l'Enclairage) system XYZ (tristimulus values) Z value. Express values for three or more samples.	Continuous efforts will be made in the future to establish appropriate measurement conditions to enhance reliability so that they may be included in the compulsory test items.
b. Brightness	After preparing the sample in the same manner as for Hunter whiteness test, determine the L value of the Universal Chromaticity Scale system L, a and b. Express average values of three or more samples.	

Test	Testing Method	Comments
c. Drip under pressure c. Drip (cont.)	Place 50 grams of thawed surimi into a cylinder with a diameter of 35 millimeters and a length of 150 millimeters. Apply initial load of 500 grams, then another 500 grams after five to 10 minutes. Maintain the load for 20 minutes, then determine the amount of liquid dripping. Express the amount of drip liquid against the sample in weight percentage.	Use naturally thawed surimi for drip measurement. Cylinder will have numerous 3-millimeter holes in the bottom.
d. Viscosity	To 153 grams of thawed surimi, add 857 milliliters of 3.5 percent salt water (for unsalted surimi the final salt amount is 3 percent, meaning that for salted surimi the concentration of the salt water must be adjusted to create a final salt content of 3 percent). Place this solution in a cooling and foam — preventing mixer	3.5 percent salt water should be cooled to 10 C. A 50-50 percent blend is acceptable too. The mixer is specially made to

Test	Testing Method	Comments
d. Viscosity (cont.)	(Mitsubishi M310 model) for blending at scale 1 for 8 minutes, liquid temperature 8 to 10 C. After leaving the mixture for 40 minutes, use a Brookfield viscometer (Tokyo Keiki Type C) to measure viscosity at liquid temperature 10 C +/- 0.5 C	order.
B. Kamaboko test		This test produces kamaboko from surimi under defined conditions for evaluating the gel-forming ability of the surimi.
1. Preparation of test samples		
a-1. Non-starch samples	Finely chop 3 to 5 kilograms of half thawed surimi, using a grinder or silent cutter (≈ 5 minutes), then add salt equal to 3 percent of surimi weight. Blend into the fish paste. (Note time blended. Use the grinder up to 30 minutes; the silent cutter up to 15 minutes.	Keep the temperature of the finished meat paste under 10 C.

Test	Testing Method	Comments
a-2. Starch added samples	Use the same procedure adopted with the non-starch samples; add 3 or 5 percent potato starch to the meat paste (in terms of surimi weight), blend for a suitable time to finish as meat paste.	Potato starch should be used. Note the amounts being added.
b. Filling	Pack about 150 grams (about 20 centimeters long) of meat paste into a 48-millimeter diameter folded vinylidene chloride film (saran casing or kureha casing), then bind both ends.	The packed casing is not subjected to a setting ("suwari") process as a general rule. When such a process is conducted, note the specific conditions involved.
c. Heating	Heat for 30 or 40 minutes in 90 C hot water.	
d. Cooling	Dip in cold water immediately after the heat processing, then place at room temperature after sufficient cooling.	

Test	Testing Method	Comments
2. Quality judgement methods	For test products produced as described above, conduct the following measurements within 48 hours. Temperatures of test samples should be between 20 and 30 C.	Optimum measuring temperature is in the range of 20 C.
a. Jelly strength	Use either the Okada gelometer or the rheometer to determine jelly strength. Plunger diameter should be 5 millimeters. Test samples should be cut into round-shaped slices of length (height) 25 millimeters, then remove film and use as test specimen. Place the test specimen on the measuring equipment sample base so that the center of the slice surface is directly below the plunger. Apply load to the plunger at a set speed.	The larger the plunger diameter the greater the variation in force (W:g); the smaller the diameter the greater the variation in depression (L:cm). The diameter of the sliced test specimen should be approximately 30 millimeters. Note the type of measurement equipment used for testing.

Test	Testing Method	Comments
a. Jelly strength (cont.)	When the test specimen loses its resistance and ruptures, measure the load (force strength) and the depth of depression. Express force strength with "W" in units of grams. Express depression depth with "L" in units of centimeters. Express jelly strength with W x L value in units of grams x centimeters. Obtain test specimens from three or more tests. Express the average measurement value for each one.	
b. Hunter whiteness	Cut test samples into round-shaped slices of a suitable length (height) to make test specimens. Measure whiteness of surface and test specimen with a color difference meter (whiteness meter).	The color difference meter (whiteness meter), measurement and value expression methods are the same as those used in optional test 2a.

Test	Testing Method	Comments
b. Hunter whiteness (cont.)	Express average values for three or more test specimens.	
c. Brightness	Cut test samples into round-shaped slices of a suitable length (height) to make test specimens. Measure whiteness of the surface of the test specimen with a color difference meter (whiteness meter). Express average values for three or more test specimens.	The measurement and value expression methods are the same as those used in optional test 2b.
d. Sensory	Use as test specimens round-shaped slices cut 5 millimeters thick. Conduct tests through a 10-point method, with a panel of three or more skilled testers. Evaluations should focus on strength	

Test	Testing Method	Comments
d. Sensory (cont.)	(texture) and pliancy (elasticity) when chewed, with evaluation points expressed in terms of structural strength. Evaluation is by a 10-step method: **Points** — **Structural strength** 10 — Extremely strong (full texture) 9 — Very strong 8 — Strong 7 — Slightly strong 6 — Normal 5 — Slightly weak 4 — Weak 3 — Very weak 2 — Extremely weak 1 — Fragile (fish ball-like or olay-like)	

Test	Testing Method	Comments
e. Folding test	The test piece is held between the thumb and forefinger and folded to observe the way it breaks. The test specimen should be cut into a round-shaped slice 3 millimeters thick and evaluated by a five-stage method, as follows:	The test specimen thickness differs from that used in the sensory test.
	Point **Condition** 5 No crack showing after folding twice 4 No crack showing after folding in half 3 Cracks gradually when folded in half 2 Cracks immediately when folded in half 1 Breaks by finger pressure	Relationship to the conventional evaluation method is as follows: 5 = AA, 4 = A, 3 = B, 2 = C and 1 = D.

Appendix 2. Salt-Free Surimi Quality Standards

Grade	Raw Material Test			Kamaboko test (starch added)				Kamaboko test (no starch)		
	Moisture	pH	Impurities	Jelly Strength	Folding	Degree of Ashi	Whiteness	Jelly Strength	Folding	Degree of Ashi
Factory Ship Surimi	%		Score	g.cm (3% starch)	Score	Score	Degree	g.cm	Score	Score
1	75.0±0.5	>7.0	10.0	>900	10	10	>60.0	>680	10	10
2	75.0±0.5	7.0	>9.0	>900	10	9	>59.0	>680	10	9
3	75.0±0.5	7.0	>8.0	>850	>8.5	>8.0	>58.0	>640	8.5	>8.0
4	75.0±1.0	7.0	>6.0	>700	>7.5	>6.0	>55.0	>520	7.5	>6.0
5	75.0±1.0	7.0	>5.0	>600	>7.0	>5.0	>54.0	>440	7.0	>5.0
6	76.0±1.0	7.0	>4.0	>450	>6.5	>4.0	>50.0	>310	6.5	>4.0
Shore Plant Surimi				force strength only (g)				force strength only (g)		
special	77	—	—					350g	10	
1	78	—	—	(3% added) 330	10	—	—	—	—	—
2	79	—	—	300	(5% added) 10	—	—	—	—	—
out of grade	80	—	—	(10% added) 300	10	—	—	—	—	—

Appendix 3. List of Suppliers

(Lists include only those companies that provide specified equipment; non-specified equipment is available from these or other suppliers.)

Stephan Machinery Corporation
1775 Westbelt Drive
Columbus, Ohio 43228
(Vacuum cutter-mixers for gel preparation)

Hunter Associates
11491 Sunset Hills Road
Reston, Virginia 22090-5280
(Hitch tiles for color measurement)

Piedmont Plastics Inc.
P.O. Box 26006
Charlotte, North Carolina 28221
(Plastic discs for torsion test)

Gel Consultants, Inc.
4205 Weaver Drive
Raleigh, North Carolina 27612
(Tubes for gel preparation; complete equipment for torsion testing)

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