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Large and Small Deformation Studies of Ohmic and Water-Bath Heated Surimi Gel by TPA and Creep Test

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Abstract Interrelationship between results of large deformation (texture profile analysis, TPA) test and small deformation (creep) test on ohmic heated surimi gel, water-bath heated surimi gel, and commercial fish gel products (*kamabokos*) was examined. Creep test revealed ohmic heated gels have higher elastic modulus and viscosity values than water-bath heated ones, with differences of elastic modulus and viscosity between ohmic and water-bath heated gels being 18 and 28.5%, respectively. These differences were reflected in the higher hardness, cohesiveness, and chewiness values of ohmic heated gels in TPA. In TPA test, the differences of hardness and chewiness between ohmic heated gel and water-bath heated gel were 29.3 and 38.7%, respectively. It was concluded that with proper experimental design, the small deformation creep test which gives molecular level deformation data can be related to the large deformation TPA test indicating the sensory textural properties.

Keywords: texture profile analysis, creep test, fish gel, ohmic heated surimi, water-bath heated surimi

Introduction

Gelation is an important factor for determining the textural properties of surimi gel. Gel strength of fish gel products (*kamaboko*) made from surimi has been improved when it was ohmically heated as compared with *kamaboko* heated in a water-bath (1-3), and ohmic heated liver paste, country-style meat loaf, and ham had been found to be acceptable by trained panelists (4).

Improved gel functionality was accompanied by retention of myosin heavy chain, which indicated that the proteolytic activity of endogenous protease was minimized by rapid heating associated with ohmic heating (3). This could be achieved through new hydrophobic interactions created by the rapid heat denaturation, especially disulfide bonds, as reported by Choi and Lee (5).

Texture profile analysis (TPA) is widely used for rheological testing of a variety of foods and gives information about the mechanical properties of foods in large scale deformation. Although the mechanical properties depend on the strain and the rate at which the deformation occurs, TPA test is capable of providing measurements that correlate extremely well with sensory texture profile data, and gives a good measure of binding properties or cohesive properties of gel materials (6, 7).

Rheological studies of model systems for foods are commonly performed using small-deformation measurements, and these measurements can provide important data related to physico-mechanical changes in microstructure (8, 9). Creep test is one of the powerful small-deformation measurement methods due to its simplicity in analysis, and provides better understanding of models that are involved (5, 10, 11).

Foods, in general, have relatively non-homogeneous microstructure and, therefore, linear range of viscoelastic behavior is extremely narrow. Due to these characteristics, adaptation of data acquired from small scale deformation test to texture analysis, which is generally carried out by applying large scale deformation accompanied with structure deformation, is not a simple task (12, 13). Therefore, comparison between creep test (small deformation test) and TPA test (large deformation test) results may be theoretically unjustifiable. But it is considered very meaningful if one establishes the effect of structural changes in food materials acquired from small deformation test to sensory rheological texture characteristics, which can be identified by large scale deformation test. However, very few reports of large deformation measurements, as compared with studies of small deformation, can be found (14).

The objectives of this study were to compare the differences of rheological properties between water-bath and ohmic heated surimi gels by TPA and creep measurements, and to investigate the interrelationship between large and small scale deformation tests by comparing the results of creep test, which provides information of alteration at molecular level, to those of TPA test, which has high correlation with sensory characteristics.

Materials and Methods

Materials Grade FA frozen Alaska pollock (*Theragra chalcogramma*) surimi was obtained from Dongwon Industries Co., Ltd. (Seoul, Korea). Crude protein and moisture contents were measured by Kjeldahl method and AOAC, respectively (15). Typical commercial fish gel products were purchased from a local market in Seoul, and the samples were carefully selected to have expire dates within two days apart. They were placed on plastic plates wrapped with film, and stored in a refrigerator.

Sample preparation Frozen surimi samples were

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thawed at room temperature for 2 hr and cut into small pieces. Batches of surimi (500 g) were chopped in a table top cutter blixer (Robot Blixer 5A; Coupe S.A., France) at low speed for 1 min. Salt (2%, w/w) was added, and mixed with surimi for another 1 min. Then, ice was added to adjust final moisture content to 81%, and the samples were further chopped at high speed for 1 min. The surimi paste was kept at < 8°C at all times. An aliquot of the paste (45 g) was pushed into acrylic template mold and then loaded by 15 kg block until the proper form was acquired (6× 5×1.5 cm) (5). The samples were used for ohmic and water-bath heating.

Water bath heating procedure For water-bath heating, the samples (6×5×1.5 cm) were wrapped with food packaging wrap (Clean Wrap, Cleanwrap Co., Korea), and heated in a 90°C water bath. Changes of temperature at the geometric center of the sample were measured using a T-type thermocouple, and recorded every 1 sec by datalogger (Hydra 2625A; Fluke Co., Germany) (5). The other paste was stuffed into PVC box and heated using an ohmic heating apparatus. Water-bath heated surimi gels were placed on plastic plates wrapped with film, and stored in a refrigerator.

Ohmic heating apparatus An ohmic heating apparatus was developed. The apparatus was constituted with a PVC box (6×5×5 cm) with two titanium panels attached at each end of the box to be used as electrodes, a signal generator (AG-204; Kenwood Co., Japan), a power amplifier (4025; NF Co., Japan), and a datalogger (Hydra 2625A; Fluke Co.). A hole (Φ 2 mm) was drilled at the center of the PVC box to be used as a thermocouple port and all the joint parts of the panels were completely sealed with a glue. To measure temperature at the geometric center of the sample, type-T thermocouple covered with teflon to prevent interference from the electrical field was used. Sixty-Hz alternating current at 240 V was supplied to a power amplifier. Datalogger was used to measure voltage and current through and across the sample (5).

Ohmic heating procedure A surimi paste was placed on the sample holder, and the sample holder was filled with the sample (6×5×1.5 cm) in close contact with the electrodes. The surimi paste was heated to 90°C using alternating current of 3 kHz at the voltage gradient of 7.7 V/cm. Temperature, voltage, and current changes during heating were recorded at 1 sec intervals by a datalogger (Hydra 2625A; Fluke Co.) (5). Surimi paste is a homogenous material and electrical field was assumed to be uniform across the sample, thus temperature variation within the sample was neglected (3). Ohmic heated surimi gels were placed on plastic plates wrapped with film, and stored in a refrigerator

TPA test For TPA test, cylindrical samples (12.4 mm in dia.; 10 mm in height) were cut with a cork borer to 10 mm thick slices. TPA test was carried out using a Texture Analyser (TA-XT2i; Stable Micro System, UK.) in combination with a 25 kg load cell. TPA mode was used to compress commercial fish gel products, ohmic and water-bath heated surimi gels twice with a Φ 25 mm compression plate and a heavy duty platform at deformation of 70% of the original sample height (1.0±0.1 cm). The cross-head speed was set at 2.4 mm/sec (16). Six measurements were taken on each sample for each test.

Creep test For creep test, cylindrical samples (35 mm in dia.) were cut with a cork borer to 3 mm thick slices of the *kamaboko*, ohmic and water-bath heated surimi gels. Creep behavior under compression was analyzed using a Haake Rheometer (RS 150; Haake Inc., Germany) in combination with serrated parallel plate geometry (35 mm in dia.). Based on preliminary results, measurements were made within the linear range with constantly applying 30 Pa to the gels. Creep and recovery were measured for 480 sec, respectively. Silicon oil was applied on the exposed surface of gel samples to protect evaporation of water within samples and temperature was controlled at 20°C using a water-circulated temperature control unit (5). All measurements were replicated at least six times. The obtained creep compliance $\varepsilon(t)$ was analyzed by the four-element Kelvin model using the following equation:

$$\varepsilon(t) = \sigma_0/E_0 + \sigma_0/Er(1-\exp^{-t/Tr}) + \sigma_0 \times t/\eta_N$$

where, σ_0 is the initial constant stress, E_0 is the elastic modulus of a Hookean body (Pa), Er is the elastic modulus of the Voigt body (Pa), Tr is retardation time (sec), and η_N is the viscosity of the Newtonian body (Pa·sec) (17).

Results and Discussion

Rheological properties of ohmic and water-bath heated surimi gels by TPA and Creep test Creep and recovery creep compliance curves for ohmic and water-bath heated gels were compared (Table 1). The elastic modulus (Er) and viscosity (η_N) were 10.40 kPa and 4802.09 kPa·sec for ohmic heated gel, and 8.52 kPa and 3434.72 kPa·sec for water-bath heated gel, respectively. The elastic modulus and viscosity of ohmic heated gel were 18 and 28.5% higher than those of water-bath heated gel respectively. Retardation time (Tr) of ohmic heated surimi gel was longer than that of water-bath heated gel. These results imply that the ohmic heated surimi gels were more rigid and less fluid than water-bath heated surimi gels.

Hardness, cohesiveness, springiness, and chewiness of ohmic and water-bath heated surimi gels were measured by Texture Analyser at a cross-head speed of 2.4 mm/sec and a 70% compression ratio; these instrumental conditions were found to be highly correlated with sensory measurements in preliminary tests (16) (Table 2). The hardness,

Table 1. Viscoelastic parameters of ohmic and water-bath heated surimi gels by creep test

	Ohmic heating	Water-bath heating
Er[1] (kPa)	10.40	8.52
η_N[2] (kPa·sec)	4802.09	3434.72
Tr[3] (sec)	51.8	49.0

[1]Instantaneous elasticity + retarded elasticity.
[2]Newtonion viscosity + retarded viscosity.
[3]Retardation time.

cohesiveness, and chewiness of ohmic heated surimi gel were 29.3, 14.1, and 38.7% higher than those of water-bath heated gel, respectively. Yongsawatdigul *et al.* (3) reported that shear stress and strain values, which were correlated with gel hardness and cohesiveness, of surimi gels heated ohmically were more than twice the values of conventionally heated surimi gels. Shiba and Numakura (2) also illustrated that Walleye pollock surimi heated by ohmic heating for 1 min exhibited a 33.1% increase in gel strength compared with that heated conventionally for 50 min.

Relationships between TPA and Creep measurements

Relationships between TPA and Creep measurements were investigated based on the results of TPA and Creep measurements of ohmic and water-bath heated surimi gel, and typical commercial fish gel products.

Creep test, in which measurements are carried out within a very small deformation range (within the linear viscoelastic range), is widely used for acquisition of physicochemical microstructure information of molecules (7, 12, 13). TPA test, on the other hand, is a large scale deformation test, and is closely related to sensory textural property which is necessary to structural destruction (18).

The elastic modulus and viscosity of ohmic heated gel were higher than those of water-bath heated gel. The elastic modulus difference between ohmic and water-bath heated gels was 18.1% (Table 1), and this value was similar to the difference (16.4%) of elastic modulus among four kinds of commercial fish gel products (Table 3). On the other hand, the differences (28.5%) in the viscosity between ohmic and water-bath heated samples were much higher than those (13.9%) among commercial products. In the case of TPA test, hardness, chewiness, and cohesiveness of ohmic heated gel were higher than those of water-bath heated gel. The hardness and chewiness differences between ohmic and water-bath heated gels were high with values of 29.3 and 38.7%, respectively (Table 2). This is a significant difference when compared with the results acquired among four commercial fish gel samples, which were 20.5% for hardness, and 36.3% for chewiness (Table 4). These differences of hardness and chewiness among four commercial fish gel samples showed also significantly different by sensory evaluation (16). These results indicate that the differences in viscosity between ohmic and water-bath heated surimi gels by creep test were related with the differences in hardness and chewiness between the samples measured by TPA test.

It is true that stress relaxation test, a small-scale deformation test, along with creep test should be applied to Maxwell model after being tested within the strict linear viscoelastic range. But in the case of food, previous researches have relied on results from wide linear viscoelastic range or, in some cases, totally disregarded them (19-23).

Fundamentally, small scale deformation test (within 5% deformation) and large scale deformation test (greater than 20-30% deformation) have very different experimental condition so that comparing their results may be unreasonable and meaningless. However, when both tests were carried out under same deformation test condition which was approximately at 20% linear viscoelastic range instead of strict linear viscoelastic range, significant correlation relationship was found between variables of TPA test (large deformation test) results and stress-relaxation test (small deformation test) results (5).

In conclusion, microstructural differences were found between ohmic and water-bath heated gel by creep test. These differences were also observed in TPA test, in which trends significantly correlated with sensory texture profile data. Previous study (5) demonstrated that disulfide bond and non-covalent bonds contribute to the rheological differences between ohmic and water-bath heated gel. Thus, these bonds may contribute to stabilization of ohmic heated gel network structure, and they would develop elastic and especially, viscoelastic parts inside the gel network, which were consistent with data by creep test. Therefore, the reason for differences in cohesiveness, especially chewiness, and hardness between ohmic and water-bath heated gel by TPA test may be due to differences in the levels of disulfide bonds. Stabilization of

Table 2. Textural parameters of ohmic and water-bath heated surimi gels measured by Texture Analyser with 70% compression ratio and 25 mm probe diameter at cross-head speed of 2.4 mm/sec

	Hardness	Cohesiveness	Springiness	Chewiness
Ohmic heating	2314.614 ±219.131	0.481 ±0.018	0.742 ±0.011	826.858 ±95.185
Water-bath heating	1636.750 ±135.382	0.413 ±0.031	0.748 ±0.020	507.250 ±71.831

Table 3. Viscoelastic parameter data of 4 different kinds of commercial fish gel products (*kamabokos*) by creep test

	Da[1)]	Do	Sa	Ko
Er[2)] (kPa)	44.63	43.79	37.30	42.73
η_N[3)] (kPa·sec)	23112.15	24395.01	23787.40	26848.38
Tr[4)] (sec)	57.1	55.8	53.6	54

[1)]Identification of the manufacturer of the samples.
[2)]Instantaneous elasticity + retarded elasticity.
[3)]Newtonion viscosity + retarded viscosity.
[4)]Retardation time.

Table 4. Textural parameters of commercial fish gel products (*kamabokos*) measured by Texture Analyser with 70% compression ratio and 25 mm probe diameter at cross-head speed of 2.4 mm/sec

	Da[1)]	Do	Sa	Ko
Hardness (kg)	5292.243 ±246.800[2)]	4207.924 ±118.780	4304.483 ±356.183	5016.229 ±322.595
Cohesiveness	0.532 ±0.005	0.512 ±0.003	0.533 ±0.005	0.551 ±0.003
Springiness	0.865 ±0.010	0.840 ±0.020	0.882 ±0.008	0.886 ±0.017
Chewiness	2435.399 ±144.168	1562.211 ±63.991	2026.313 ±190.197	2452.645 ±182.470

[1)]Identification of the manufacturer of the samples.
[2)]Values are means±standard deviation of each sample.

network structure by disulfide bond and non-covalent bonds may result in higher cohesiveness, especially chewiness, and hardness of ohmic heated gel as compared to those of water-bath heated gel.

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