かまぼこの足の測定温度依存性

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Temperature Dependence of Elasticity of Kamaboko

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Temperature dependence of the elasticity of fish flesh gel, kamaboko, was studied. Kamaboko from Alaska pollack frozen surimi underwent different elasticity measurements in the range of 0–80°C. In puncture and chewing tests, breaking force and hardness were slightly increased on raising the temperature from 20°C to 40°C, but remarkably decreased on further rise in temperature. In both the extension and compression relaxation measurements, the instantaneous elastic modulus was decreased on raising the temperature from 0°C to 80°C. Moreover, in the extension and compression creep measurements, the instantaneous elastic modulus was decreased as described above, though significant decrease was hardly recognized for the compression case at lower side of the temperature. The shear storage modulus and loss modulus were decreased by rising temperature, but increased again on lowering the temperature. In this case, the hysteresis was clearly observed between the temperature and both the moduli.

The contractile force of extended fish flesh gel, kamaboko, is strengthened by rising temperature,[1] and in the compression stress relaxation measurement, the instantaneous elastic modulus is increased with rising temperature (The modulus is described in that paper as if it is decreased, because its value is converted to the absolute value.)[2] Furthermore, from another finding that the relation of stress and strain of kamaboko is well explained by application of the rubber elasticity theory,[3] it has been believed that the elasticity of kamaboko is due to entropy force which is caused by thermal motion of protein network structure and strengthened with rising temperature. In addition, it has recently been found that the shear modulus of actomyosin gel is increased by lowering the temperature from 80°C to 20°C[4] and that the shear storage modulus of kamaboko decreases as temperature rises.[5,6] However, the last two facts suggest that kamaboko is energy elastic body, the elasticity of which is caused by bonding force among atoms or molecules and weakened on rising the temperature in contrast with the entropy elasticity. Here, we describe the temperature dependence of the elasticity of kamaboko measured by different methods.

Materials and Methods

Preparation of Kamaboko

Non-salted frozen surimi (Taiyo Fisheries, SA-grade) of Alaska pollack, *Theragra chalcogramma*, was thawed in a refrigerator and ground at 4°C for 10 min in a mortar with water 30% (w/w) and NaCl 3% to the surimi. The resulting viscous fish flesh paste was packed into a plastic cylinder (diameter: 1.4 cm, height: 1.9 cm), whose bottom was closed with a rubber-stopper, heated to gel at 80°C for 20 min in a water bath after sealed with a thin film (Saran wrap) and cooled at room temperature for 2 h. The product was pulled out from the cylinder by the aid of a needle and cut to 1 cm height with a knife after inserted to the same length of another cylinder. The pulled out columnar sample underwent different elasticity measurements. Examination was repeated 6 times at each temperature.

Elasticity Measurements

Puncture test and chewing test were carried out using a food rheometer (Fudoh Kogyo, NRM2010J-CW) in which the sample plate was equipped with a small incubator (regulated with a thermister at temperature precision of ±2°C). The sample was painted with paraffin liquid to prevent the evaporation of water during the test. The measurement was started after the sample was incubated for 10 min (plunger: globular type, diameter: 7 mm, speed: 6 cm/min). In the case of the chewing test, the lower side of the sample was

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bonded previously to the bottom of the incubator with an instant binding agent (Toa Gosei Kagaku, Bond Aron Alpha) and the plunger was driven up and down (clearance of the plunger: 5 mm). The time dependance of extension or compression force was recorded successively with an electronic multirecorder.

Extension and compression stress relaxation measurements were carried out using the rheometer equipped with a small 3% NaCl-water bath (temperature precision: ±2°C). In the extension measurement, and also in the extension creep measurement, the sample was bonded previously between the plunger and the bottom of the bath. The measurement was started after the sample was immersed to the bath for 10 min (plunger: disk type, diameter: 20 mm, speed: 6 cm/min, strain: 0.25 cm/cm). The weight of the sample was checked before and after the immersion to the bath, because the swelling of the sample, if it occurs, would result in lowering the elasticity. The elastic modulus was calculated by neglecting the change in the cross sectional area of the sample upon the extension or compression. This was the same also in the creep measurements.

Extension and compression creep measurements were carried out using a creep meter (Yamaden, Rheoner RE-3305) equipped with a water bath. The weight of 30 g was loaded to the sample after immersion for 10 min (plunger: disk type, diameter: 20 mm, speed: 0.5 mm/s) and its elongation or shrinkage was recorded automatically.

Shear storage modulus (G′) and loss modulus (G″) measurements were carried out using a dynamic rheolometer (Toyo seiki, Rheolograph-sol No. 653, cell: 40×15×2 mm, blade: 20×10×0.5 mm, vibration number of the cell: 3 Hz, shear strain: 0.01).

The cell packed with the fish flesh paste was fixed to the rheolometer and heated to gel at 80°C for 20 min with an electric heater attached to it (temperature precision: +1°C). The storage and loss moduli of the resulting kamaboko were successively recorded by vibrating the cell, till their value reached constant (about 30 min). Then, the temperature of the cell was lowered to room temperature at the interval of 10°C. After preincubation at the prescribed temperature for 10 min, the vibration of the cell was started. The temperature was risen reversely at the same interval after the recording at room temperature was finished, and the measurement was repeated once more.

Results

As shown in Fig. 1, no significant difference was detected in the breaking strain (BS) measured at different temperature, but the breaking force (BF) was slightly increased on the rise of the temperature from 20°C to 40°C. The same tendency was observed in the texturometer pattern illustrated in Fig. 2, where the hardness (H) was slightly increased on rising the temperature from 20°C to 40°C. Both the breaking force and the hardness, however, were remarkably decreased on further rise of the temperature. The results of stress relaxation measurements are shown in Fig. 3 (left). In both the extension and compression measurements, the instantaneous elastic modulus

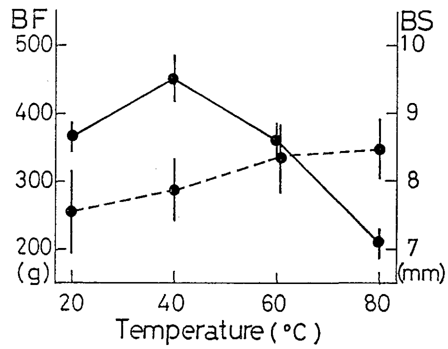

Fig. 1. The temperature dependence of the breaking force (BF) and breaking strain (BS) of the kamaboko from Alaska pollack frozen surimi.
—●—: BF, --●--: BS.
The vertical bar shows standard deviation.

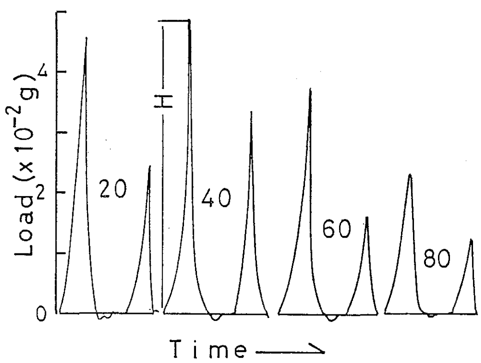

Fig. 2. The temperature dependence of the texturometer pattern of the kamaboko.
H: hardness
Figures in each pattern show the temperature (°C). The mean and standard deviation of the hardness (H) are as follows: 399±34(g) at 20°C, 506±47(g) at 40°C, 383±56(g) at 60°C and 241±28(g) at 80°C.

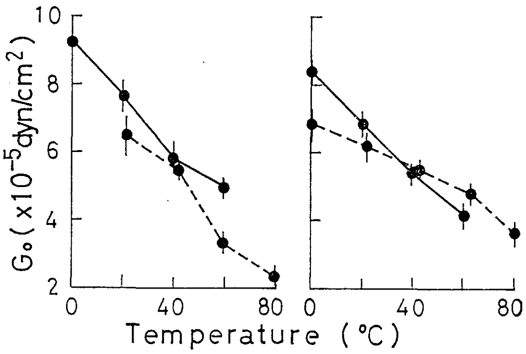

Fig. 3. The temperature dependence of the instantaneous elastic modulus (Go) obtained by stress relaxation (left) and creep (right) measurements of the kamaboko.

—●—: extension, - -●- -: compression.

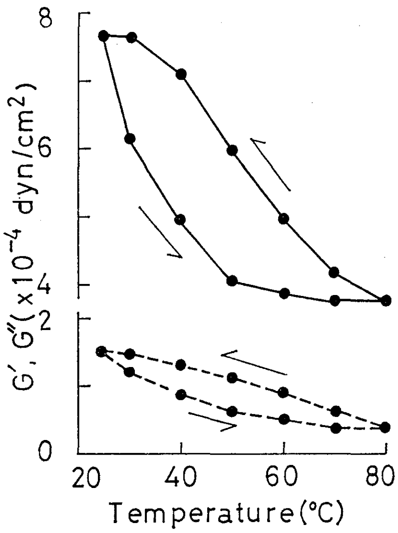

Fig. 4. The temperature dependence of the storage modulus (G′) and Loss modulus (G″) of the kamaboko.

The measurements were carried out on the same sample, first by lowering the temperature and next by rising it.

—●—: G′, - -●- -: G″.

(Go) was gradually decreased as the temperature was risen. Almost the same tendency was observed also in the creep measurements as shown in Fig. 3 (right), though significant decrease was hardly recognized for the compression at lower side of temperature. The immersion of the sample to the 3% NaCl-water bath increased its weight by 6.7% at 0°C and 20°C, 4.8% at 40°C, 4.3% at 60°C and 4.0% at 80°C. Both the storage modulus (G′) and loss modulus (G″) were increased by lowering the temperature as shown in Fig. 4 but they were decreased again by rising the temperature. In this case, the hysteresis was clearly observed between the temperature and both the moduli.

Discussion

With a few exception, almost all the elastic constants are lowered by rising temperature. This lowering, however, is not considered to be caused by the swelling of the sample during its immersion to 3% NaCl, because the weight of the sample was increased more abundantly at the lower side of temperature. Kamaboko seemes to be an energy elastic body, considering these results and the previous findings that the shear modulus of actomyosin gel[4] and the storage modulus of kamaboko[5,6] were increased by rising the temperature, the latter of which was reaffirmed in Fig. 4. On the other hand, it is known that the hydrogen bonds are thermo-unstable, which is the why the gelatin gel known as an entropy elastic body is molten at high temperature. It is nothing strange that kamaboko behaves like the energy elastic body, if the thermo-unstable hydrogen bonds play an important role in the stabilization of protein network structure. However, kamaboko can not be concluded here to be an energy elastic one, because its elasticity may be lowered merely by the cubical expansion induced by heating (The contactile force of the extended rubber is known to be weakened reversely with the rise of the temperature owing to its thermal expansion, if its extension is slight). In any case, it can be mentioned alone that in the elasticity measurement of kamoboko, the temperature should be well regulated.

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