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Studies on the Rheological Property of Korean Noodles

I. Viscoelastic Behavior of Wheat Flour Noodle and Wheat-Sweet Potato Starch Noodle

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한국 재래식 국수류의 유체 변형성에 관한 연구

제 1 보 : 밀국수와 냉면국수의 점탄성

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Abstract

The viscoelastic behavior of traditional Korean noodles was examined by using a tensile tester built in the laboratory. The creep test of cooked noodle strand showed that a linear viscoelastic response could be expected for a short time of creep, i.e. 120 sec for wheat flour noodle and 60 sec for wheat-sweet potato starch noodle, with the stress range between 4×10^4 and 14×10^4 $dyn\ cm^{-2}$. The elastic modulus was estimated to be 7.0×10^5 $dyn\ cm^{-2}$ for wheat flour noodle and 3.9×10^5 $dyn\ cm^{-2}$ for wheat-sweet potato starch noodle. A peculiar increase in viscosity with increasing stress, i.e. stress-hardening, was observed in the noodles studied.

Introduction

The processes wich are applied in the manufacture of traditional Korean noodle products are quite similar to that of spaghetti. In the manufacture of Korean wheat noodle, a dough made from wheat flour is extruded through dies to yield long, circular uniform strands which are then dried. Another traditional noodle, called Naengmyon, is made from the mixture of wheat flour and sweet-potato starch.

Demand currentlys exist for information on the mechanical behavior of Korean noodle products for their quality evaluation and product development. The quality of noodle products is determined essentially by the following factors: (a) color and appearance; (b) mechanical properties of the uncooked product (of special interest in the packing and transportation of noodle products); (c) behavior upon cooking (cooking loss, texture of the cooked material); (d) keeping the textural properties after cooking(1).

The textual characteristics of cooked noodle, such as firmness, chewness and springiness, determine the consumer acceptance of the product. A study on the terms describing the textural characteristics of Korean noodle products indicated that cohesiveness, elasticity and hardness were the important textural characteristics of Korean noodles(2).

Several testing methods and instruments have developed for the determination of physical properties of European pasta products (3, 4). The viscoelastic properties of flour dough have been widely tested in relation to the quality of both pasta and bakery products(5, 6). However, only a few investigators have studied the

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mechanical behavior of noodle products by using engineering terminology and techniques. Shimizu *et. al.* (7) studied the behavior of noodle under constant load, and a four-element mechanical model was selected to represent the rheological behavior of noodle.

Since the mathematical interpretation of non-linear viscoelastic behavior is difficult, it is required to examine the time and stress dependent effects of the test materials prior to apply the mechanical models. In a linear viscoelastic material the ratio of stress to strain is a function of time alone and not of the stress magnitude. Most of food materials exhibit both linear and non-linear viscoelastic response depending on the resulting strain. If the deforming stress is sufficiently small or the resulting strain is small, the linear viscoelastic response can be achieved experimetally(8).

The present study characterized the viscoelastic response of traditional Korean noodles by using a tensile tester built in the laboratory. The time dependence of stress-strain relationship in simple extension of cooked noodle strand was examined through creep and creep recovery tests. The linear viscoelasticity of the cooked noodles was tested with various stresses and times of loading.

Materials and Methods

Test samples

Commercial noodles of two different types were studied: i.e. wheat flour noodle and wheat-sweet potato starch noodle. In the manufacture of wheat flour noodle a dough was mixed from flour, salt and water and extruded through dies to yield long, circular and uniform strands which were then dried in an ambient temperature. Wheat-sweet potato starch noodle was made from wheat flour dough containing Ca, 10% of sweet potato starch. the average diameter of wheat noodle and wheat-sweet potato starch noodle were 1.52 ± 0.12*mm* and 1.02 ± 0.10*mm*, respectively.

The selected samples were cooked by direct immersion in a boiling water pot filled with ℓ of tap water maintained at 99 ± 1°C. One test sample was cooked at a time to minimize mechanical damage. Noodles were cooked for their optimum cooking time. The optimum cooking time was determined by the time when a thin white-lined core of the stick was just disappeared(4). The optimum cooking times were 6 *min* for wheat flour noodle and 3 *min* fro wheat-sweat potato starch noodle. Immediately after cooking, the samples were cooled by soaking in tap water for 3 *min* at 25°C, drained and tested within 2 *min*.

Measurements

Creep test was made on each strand of noodles by using a tensile tester, shown in Fig. 1, built by the author's laboratory. The apparatus consisted essentially of specimen support of clamps and loading assembly with which a noodle strand was streched vertically. The sample was deformed as a manner of simple elongation. the upper clamps were fixed at the top of apparatus. The most difficult problem in tension test of noodle is finding a clamping device which would hold the ends of the specimen tight without overstressing the structure. In our experiment an attempt was made to prevent specimen from damaging and slipping during loading.

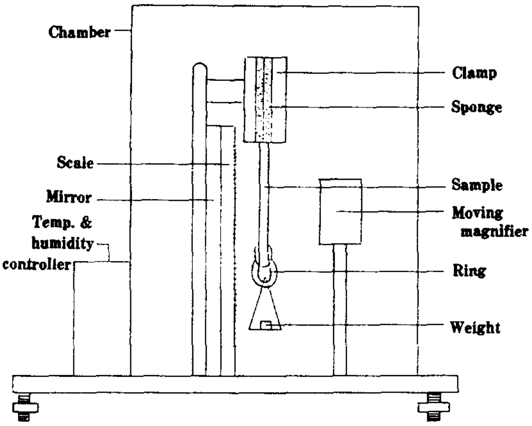

Fig. 1. Schematic diagram of the apparatus for determination of creep behavior in simple elongation.

Deformation at each time was observed through movable magnifier. A fine scale was attached to a mirror to minimize reading errors. The smallest division of the scale was 0.02*cm*, in length, and reading to one-tenth of this can be estimated with a fair degree of accuracy. Temperature was controlled at 25 ± 1°C in the test chamber by heating the outside wall of apparatus with an electric heater. To prevent dehydration of specimen during testing the relative humidity in the chamber was maintained to 99 ± 1% by using a humidifier.

A strand of noodle was clamped and 15 *cm* length of remainder allowed to hang. 10*cm* length of the lower end was then wraped around the ring so that tension was applied to 5*cm* length. With extension methods there were difficulties in achieving uniform stress close to the ends of the sample where the stress was applied. Thus, measurements of the change in length needed to be restricted to the central portion of the sample where the stress was uniform. Two fiducial marks were made on each side of the string. The position of the four fiducial marks were measured as a initial length while the strand was under zero load. To apply a very small load to specimen, different weight were placed on a ring coiled by lower strand. The load applied to the sample was calculated by the sum of the weights of ring, weights applied and 10*cm* length of noodle at each condition.

During each test, the position of the fiducial marks were read periodically. After 2000 *sec* the load was removed and the reading of the fiducial marks were continued during the recovery until the distance between marks became essentially constant. Because very small loads were used in this experiment and because the strain in the strand remained relatively small, great care was required to obtain reasonably precise data.

To derive strain-time data, the reading of the upper and lower fiducial marks, on each side of the ring, were plotted against time. A smooth curve was drawn through each set of points; then the distance between the curves at various time was obtained. From the distance at time and the initial distance between fiducial marks, the strain at each time was calculated. Each plot of strain vs. time was mean value of 5 tests.

The increases in diameter and weight of noodle by cooking were considered when stress was calculated. Ideally, a creep test should be made under a constant stress instead of under a constant load. In this paper, no attempt was made to account for the progressive increase in the true stress during the test.

Results and Discussion

Measurements of creep and crep recovery of wheat flour noodle and wheat-sweet potato starch noodle over a range of applied stresses are shown in Fig. 2 and Fig. 3, respectively

At zero time, when the stress was suddenly applied, the test piece was suddenly deformed. After this rapid reaction, the deformation continued to increase more slowly.

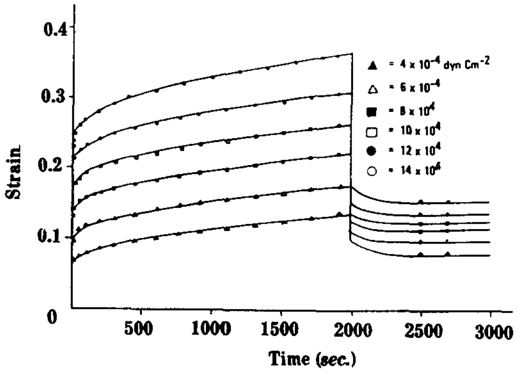

Fig. 2. Typical creep and creep recovery curves of wheat flour noodle for various levels of applied stress.

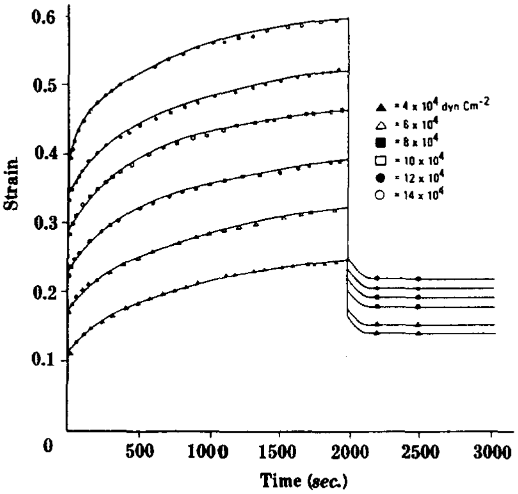

Fig. 3. Typical creep and recovery cruve of wheat-sweet potato starch noodle for various levels of applied stresses

All the creep and creep recovery curves were similar to those characteristics of non-crosslinked polymer. The strain did not approach a constant value and, therefore, there was no equilibrium compliance. The rate of displacement was falling with time in the period for which the stress applied. The rate of displacement appeared to have been approaching a constant value before the load was removed, but this condition was not reached when the stress was removed. After removal of the stress, the sample recovered some of the strain but did not return to its original condition, because there remained a permanent deformation.

In Fig. 4 and 5, the data from creep tests made by four different loads are shown as the plots of compliance against logarithmic time.

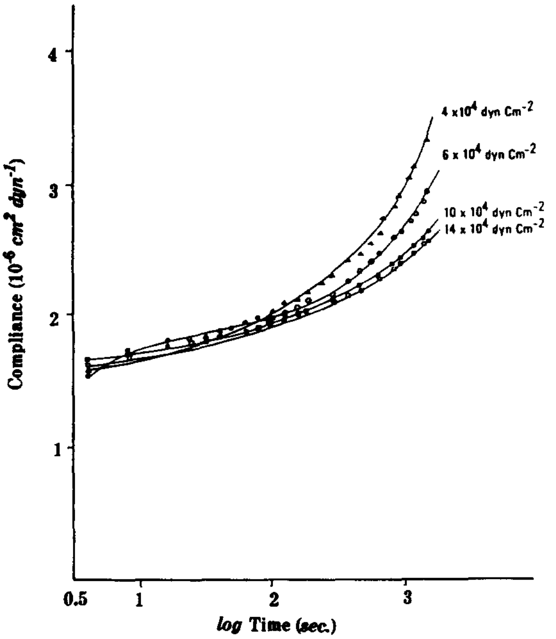

Fig. 4. Creep of wheat flour noodle as function of *log t* Data from tests under four indicated stresses.

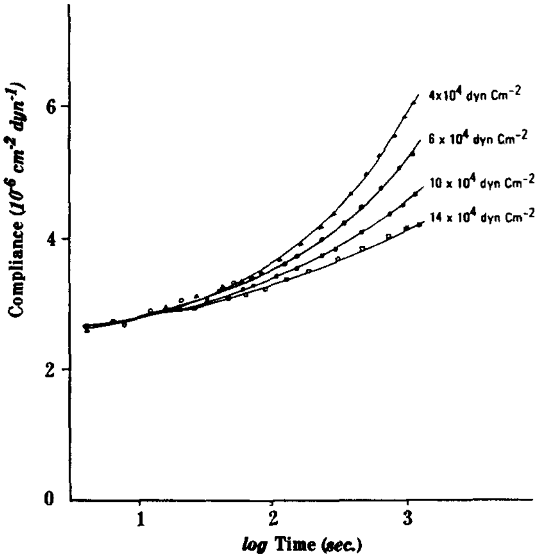

Fig. 5. Creep of wheat-sweet potato starch noodle as function of *log t* Data from tests under four indicated stresses

If noodles were a linear viscoelastic material, these logarithmic curves would be superimposed. The curves for all stresses, over the range of 4 x 10^4 to 14 x 10^4 *dyn* cm^{-2}, could be approximately superimposed for short times of creep. The approximated superposition suggested that, under certain conditions, the effect of time and stress could be separated. Within a short duration of the test period, they showed a linear viscoelastic behavior.

The magnitude of the compliance at selected times were ploted against the stresses, as shown in Fig. 6 for wheat noodle and Fig. 7 for wheat-sweet potato starch noodle.

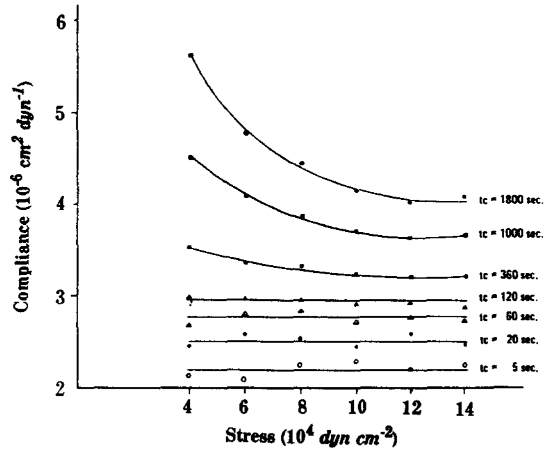

Fig. 6. Creep of wheat flour noodle plotted against applied stress at various creep time

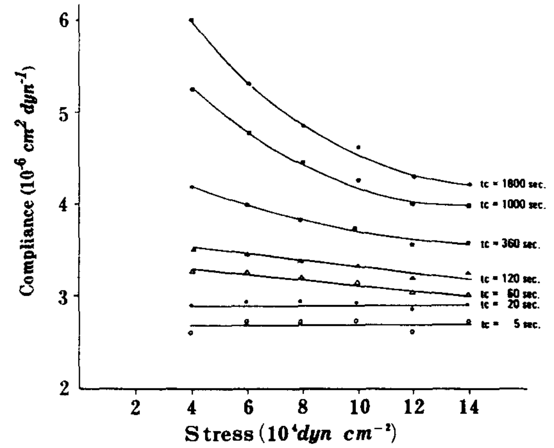

Fig. 7. Creep of wheat-sweet potato starch noodle plotted against applied stress at various creep time

A linear viscoelastic region requires that the compliance be constant over a range of stress. It appeared that for both of the noodles there was linear region when the creeping time was short. Wheat-sweet potato starch noodle showed earlier deviation from linear region than wheat flour noodle which had its linear region until 120 *sec* of creep time.

For materials whose compliance is low, e.g., metals, semicrystalline polymers, and armorphous polymers at temperature below glass temperature, linear behavior is observed at rather low value of stress and strain. In our experiment the applied stresses were high and therefore, strain showed a relatively large value. Considering these and that a rapid deformation was made at the beginning of creep test; a significant error in the measuring the deformation was quite possible, especially at the initial period of creeping.

The compliance after 2000 *sec* was divided into an elastic and viscous part in the same way as the total deformation could be divided, as shown in Fig. 8 for wheat flour noodle and Fig. 9 for wheat-sweet potato starch noodle.

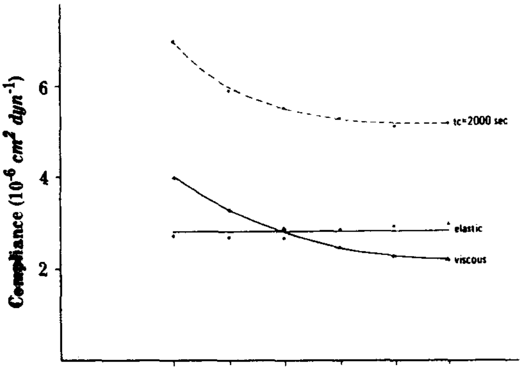

Fig. 8. Compliance of wheat flour noodle as a function of stress

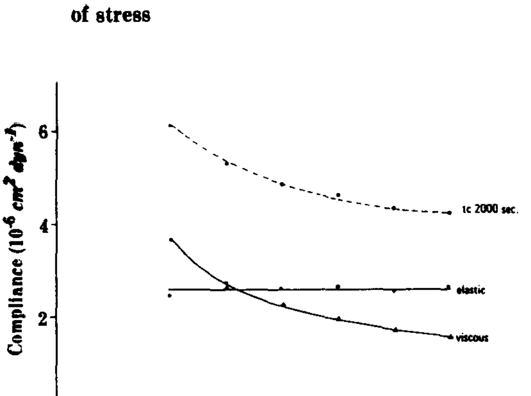

Fig. 9. Compliance of wheat-sweet potato starch noodle as a function of stress

The elastic compliance of noodle was remained constant with the stress. The elastic modulus, which is reciprocal of the elastic compliance, lied about 7.0x10^5 dyn cm^{-2} for wheat flour noodle and 3.9 x 10^5 dyn cm^{-2} for wheat-sweet potato starch noodle. In addition, the increase in viscosity with increasing stress was reflected by an decreasing viscous and total compliances in both noodles. This result was peculiar characteristics of the noodles studies, contradicting to the reports on flour dough. A decrease in viscosity with increasing stress is often observed with high-molecular weight systems. It indicates non-Newtonian viscosity. The decrease in viscosity of dough with increasing stress has already observed by Schofield and Scott Blair, and Bloksma$^{(5)}$. Glucklich and Shelef$^{(6)}$ called it stress-softening. In this study the noodles showed stress-hardening property.

The strain remaining after creep and a long recovery time are a measure of the flow that has occurred during creep. The plots of residual strain vs. stress for wheat flour noodle and wheat-sweet potato starch noodle were linear lines as shown in Fig. 10.

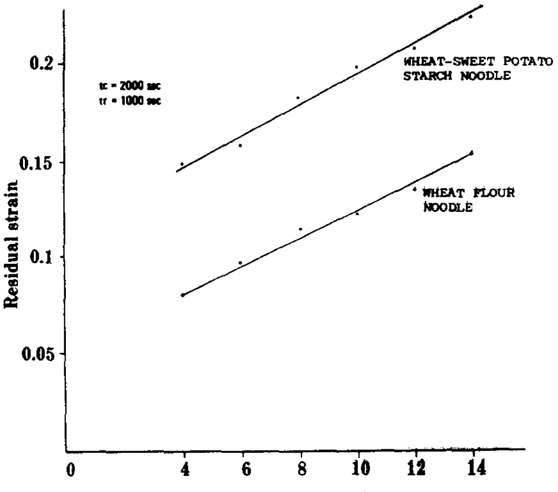

Fig. 10. Residual strain of noodles after creep for 2000 *sec.* and recover for 1000 *sec.* was plotted against applied stress

For a sample with a yield value, this residual strain would be zero for stresses below the yield value, and increase with stress for the stress above the yield value. In this experiment the smallest stress applied was 4 x 10^4 dyn cm^{-2}, and it was appeared to be too high value of stress to measure the yield stress of the noodle products.

Conclusion

The experimental results indicates that the cooked noodles exhibit linear viscoelastic behavior only within short period of creeping time when the applied stress is in the range of 4-14 x 10^4 *dyn* cm^{-2}. The viscoelastic responses varied with the type of noodle. The linear viscoelastic response could be expected within 120 sec of creeping time for wheat flour noodle and 60 sec for wheat-sweet potato starch noodle at the experimental conditions mentioned above. This fact dictates that the creep test of cooked noodles must be carried out within short period of creeping time by using small stresses less than 1 x 10^5 *dyn* cm^{-2}.

In order to apply the mechanical models, such as Kelvin, Maxwell and other complex models, for the mathematical interpretation of viscoelastic property of cooked noodles, these experimental conditions must be considered.

요 약

한국 재래식 국수류인 밀국수와 냉면국수의 점탄성을 연구하기 위하여 실험실에서 tensile시험기계를 만들고 이것을 이용하여 국수발에 대한 creep test를 실시하였다.

밀국수 및 냉면국수 모두 최초 단시간의 creep 에서는 선형점탄성(linear viscoelasticity)를 나타내었으나 creep시간이 경과함에 따라 비선형 점탄성을 나타내었다. 변형력 범위가 4 × 10^4 − 14 × 10^4 *dyn* cm^{-2}일때 밀국수는 120초간, 냉면국수는 60초간 선형 점탄성을 나타내었다.

2000초 동안의 creep시험에서 추산된 밀국수의 탄성계수(elastic modulus)는 7.0 × 10^5 *dyn* cm^{-2} 이었으며 냉면국수는 3.9 × 10^5 *byn* cm^{-2}이었다. 변형력의 증가에 따른 점성변화를 평가한 결과 밀가루 반죽에서 보고된 결과와는 정반대 현상인 stress-hardening 성질을 나타내었다.

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