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Measuring Firmness of Bread with a Simple Proximity Sensor Method

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선형 근접 센서를 활용한 식빵의 물성 측정에 관한 연구

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요 약

본 연구는 식품의 물성을 측정하기 위한 한 가지 방법으로 50 변위를 아주 정밀하게 직선적으로 측정이 가능한 linear proximity sensor(선형 근접 센서)를 활용하여 식빵의 굳기를 측정하였다. 선형 근접 센서를 장착한 기구로 몇 가지 응력(0.376, 0.543, 0.769 kPa) 하에서 식빵의 온도와 수분 함량에 따른 변형을 컴퓨터 자동 자료 수집 장치를 통하여 on-line 상태로 매초마다 자료를 수집하여 컴퓨터 자료 분석 program으로 그래프를 얻었다. 식빵에 적용한 응력과 strain의 비율은 응력이 클수록 그 값이 커지는 비 선형 점탄성체의 성질을 보였다. 이 측정 기구는 좁은 온도 범위와 작은 수분함량의 차이에 따른 식빵의 굳기의 정도에 현저한 차이가 있음을 관찰할 수 있었다. 선형 근접 센서를 활용한 이 기구는 간단하면서도 정밀하게 동적으로 식품의 물성을 측정할 수 있었고, 높은 반복성을 나타내었다. 또한 수집된 자료는 점탄성체의 특성을 설명하는 기계적인 모형으로 나타낼 수 있었다. Inokuchi의 방법을 적용하여 식빵의 물성을 모형화 하면 용수철과 완충 장치의 조합으로 타나내는 Burger's 모형에 잘 일치하였다. 본 측정 장치는 설치와 사용이 간단하여 식빵과 같은 연 식품의 물성을 측정하는데 활용이 용이하였다.

Key words : linear proximity sensor, creep test, bread.

INTRODUCTION

The texture of bread crumb is associated by the consumer with the freshness of the product. Soft yet somewhat springy bread is considered most desirable. Although food quality is ultimately evaluated with a sensory panel, it is often convenient to describe quality with more reproducible objective measurements. Over the past decades several different instruments, such as the Instron Univeral Testing Machine[1] and the Baker Compressimeter[2], have been used to measure bread firmness objectively. Several investigators showed that these objective measurements correlated reasonably well with sensory data[3~6] reviewed the recent developments and the factors affects correlation between sensory and instrumental textutre measurements.

All the instruments have advantages and disadvantages. The Instron Universal Testing Machine(UTM) is a versatile instrument which can provide stress-strain relationships under various conditions. The major disadvantage of this instrument is its high cost. On the other hand, instruments such as the Baker Compressimeter(BC) are simple and inexpensive. The major disadvantage of the BC is that is measures only a single force, and the measurements cannot be used to obtain rheological properties. Another disadvantage of this device is human error involved in reading thee data. Baker *et al.*[7] have compared bread firmness

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measurements using the UTM, the BC, and two other instruments. They concluded that bread firmness as a function of time can be well followed by all four instruments, and no instrument was clearly the most sensitive under all conditions. There are occasions when a laboratory needs to measure the stress-strain behavior of bread or similar food products, but it does not have access to the use of an UTM. There are also occasions when it is desirable to perform experiments to monitor the deformation of a sample under constant load over a long period time, and it becomes very expensive to occupy an UTM for days for one sample.

In creep experiments, a stress is suddenly applied and maintained at a constant value while strain is measured as a function of time. Creep involves a change in shape and dimension at a constant volume. It is one of the most important and widely used engineering tests of viscoelastic behavior. The measurement on bread curmb reported here were carried out to apply a linear proximity sensor as a simple and sensitive method for measurement of deformation in creep test. The obtained data were also evaluated by means of Inokuchi's method[8, 9] to provide useful information on the viscoelastic properties of bread crumb.

MATERIAL AND METHODS

1. Measurement of creep compliance

The method involves assembling a compression test unit as shown in Fig. 1. The linear proximity sensor(Baumer Electric IWA 30V90 01) measured the distance between the sensitive face of the sensor and the upper surface of a metal disc of a constant weight at real time. The linear proximity sensor has a sensing range

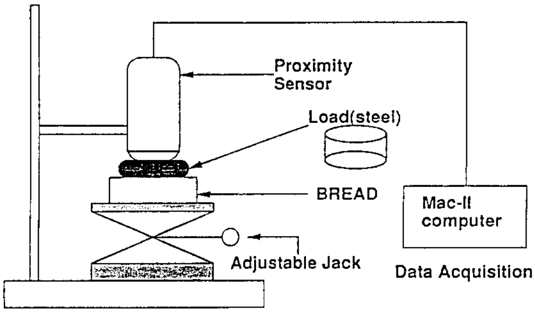

Fig. 1. Schematic diagram of compressimeter with proximity sensor.

of 4.5 to 9.5 mm and a repeatability of within 0.03 mm. The metal discs are 35 mm in diameter, and discs of four different weights(35, 53, 75, 150g) were used to provide the different stress (0.376, 0.543, 0.769 kPa).

To demonstrate the application of this method, commercial sliced white bread was prepared, its crust has been trimmed before compression. The specimens have a diameter 50 mm and thickness about 12 mm. Exact dimension of the bread were determined for each specimen with a caliper. The method will consist of carefully placing a metal disc of a constant weight on a smaple, measuring the displacement of the disc with time using a linear proximity sensor. The output of the proximity was connected to a MacIntosh Ⅱ computer equipped. The data was collected every second for a minute with data acquisition system(Strawberry Tree ACM2-12 interface board). Computer software was used for control of the machine during data acquisition and subsequent data processing. This included conversion of machine voltage vs real time output to strain with constant stress. It also included non-linear regression fitting of the data to a large variety of selected mathmetical models.

2. Analysis of compression properties

The compression properties will be obtaineed from the stress-strain curves of sample. Stress, strain, and creep compliance are defined as follows:

$$\text{Stress} = \frac{\text{Force}}{\text{Cross sectional area}}$$

$$\text{Strain} = \frac{\text{Deformation}}{\text{Thickness}}$$

$$\text{Creep compliacne} = \frac{\text{Strain}}{\text{Stress}}$$

Fig. 2 is shown the typical creep tests of viscoelastic materials which can be represented by a series of mechanical models consisting of a spring and dashpot[8]. When stress is applied, the sample exhibits pure elastic response at zero time. After this initial strain, the rate of strain decreases as the weakest linkages in the interal structrue rupture. After all the linkages have been ruptured, the rate of strain will be constant as represented by the linear part of curve. The following equation describes the system characterized above and the parameters can be determined by the Inokuchi method[9].

$$J(t)=J_o + \sum_{i=1}^{\infty} J_i \left(1-\exp\left(\frac{-t}{\tau_i}\right)\right) + \frac{t}{\eta}$$

$J(t)$: compliance at time t
J_o : instantaneous compliance(t=0)
J_i : compliance of Voigt unit
τ_i : retardation time
η : viscosity

Instantaneous compliance is the inverse of the elastic modulus of the spring element. It indicates the stiffness of the material.

RESULT AND DISCUSSION

Three difference weights were used to provide the stress levels 0.376, 0.543, 0.769 kPa, and the ratios of strain to stress(creep compliances) were shown in Fig. 3, if the test

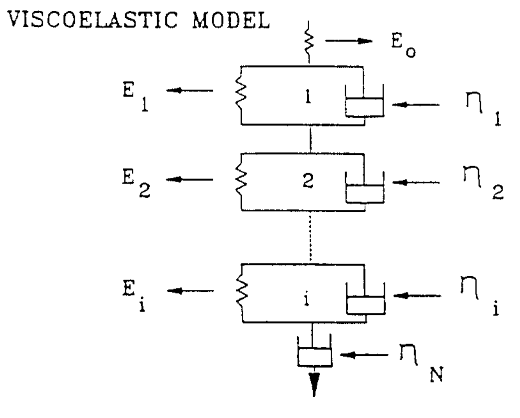

Fig. 2. Mehcanical reperesentation of a viscoelastic substance. E_i: elasticities, η_i: viscosities associated with Voigt bodies.

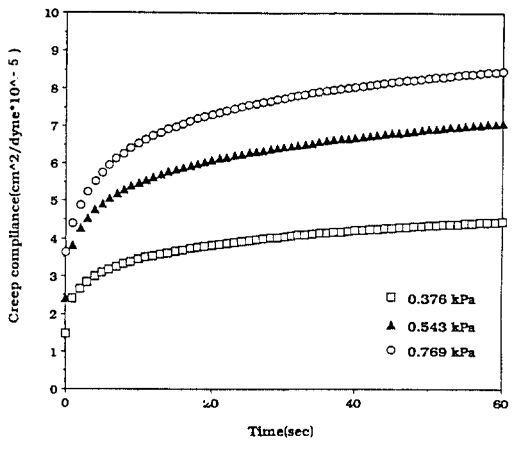

Fig. 3. Creep compliances of White Pan Bread under different stress.

matial was lineraly viscoelastic, then the tree curves in Fig. 3 should be coincidence at all time. However, the curves in Fig. 3 show that nonlinearity was present for the white pan bread. The creep compliance depended to the shearing stress and increased with increasing stress. The creep was proportional to 10 times of the applied stress over the range investigated (Fig. 4). The creep compliance of the white pan bread with different moisture level is shown in Fig. 5 at stress 0.769 KPa. The samples became less compressible as the moisture content was decreased, thus resulting in a lower creep compliance. It can be said that the degree of firmness was significantly affected by moisture content. The creep compliance of the white pan bread at different temprature is shown in Fig. 6. Although narrow range, temperature affects the firmness of the bread significantly.

Compliance measures the amount of deformation per unit stress(cm/dyne); it is the reciprocal value of the rigidity modulus. Thus the higher the compliance, the weaker the bread. There are several different mechanical models

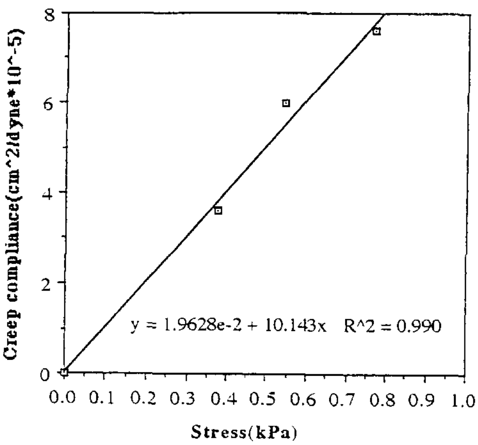

Fig. 4. Relationship between the creep compliance at 40 sec and stress level.

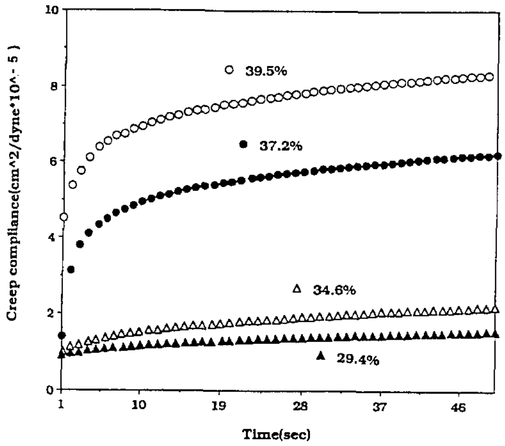

Fig. 5. Effect of moisture content on creep compliances of White Pan Bread (25℃, stress=0.769 kPa).

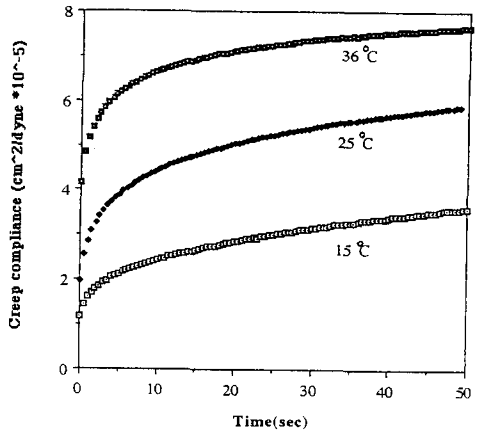

Fig. 6. Influence of temperature on deformation of White Pan Bread (stress=0.543 kPa).

consisting of spring and dashpots that are used to describe the rheological behavior of viscoelastic materials. In this experiment the result of creep compliance on bread crumb can be represented by a 4-element Bruger's model. The following equation represents the model:

$$J(t)=J_o+J_i\,(1-\exp(\frac{-t}{\tau}))+\frac{t}{\eta}$$

where J(t) is the total creep compliance at time t, Jo is the instantaneous rigidity compliance, J_1 is the retarded cmpliance, τ is the retardation time, η is the retarded viscosity associated with the retarded compliance. Using this model, all data were fitted into the creep retardation curve well as shown in Fig. 7(R^2=0.994). The compliance of each crumb was an average from 10 experiments and the values J_o, J_1, τ, η could be determined by the Inokuchi method[9]. The best estimates of the four parameters J_o, J_1, τ, η were 2.5×10^{-5} cm²/dyne, 1.88×10^{-5} cm²/dyne, 8.5 sec, 4.52×10^5 poise at 0.543 kPa stress level respectively.

The compression test unit is very inexpensive and occupies little space in the laboratory. It serves as a useful instrument for our laboratory's occasional needs for measuring soft food materials. This technique is most applicable for

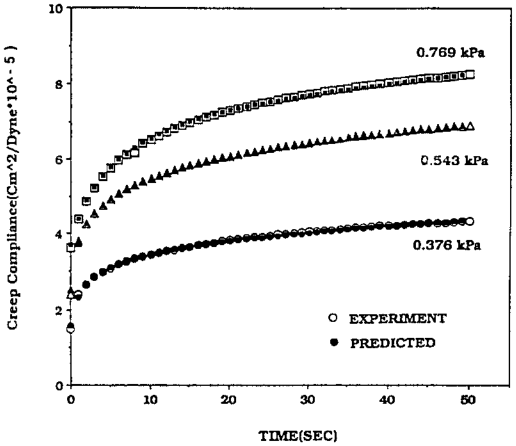

Fig. 7. Predicted and experiment creep compliances of White Pan Bread under different stress.

soft material such as bread and gel. Because it is inexpensive, many unit may be used at the same time, especilly for studies where long time is required. The use of linear proximity sensor showed its applicability as a simple and accurate measurement for textural properties of bread which is very soft.

The technique decribed here has been shown to provide good reproducible results. The measurements are shown to be converted to useful rheological parameters. The main advantage is its low cost, so that long time creep experiment for some products. The unit occupies little laboratory and can be stored easily when not in used. This technique, however, has a limitation of applicable only for soft material or gel.

ABSTRACT

This paper presents a simple method for measuring the firmness of bread using a linear proximity sensor. An apparatus which is constructed with a linear proximity sensor was used to measure the creep behavior of the bread under several constant stress level. In a creep test for bread crumb, a simple and sensitive method using a linear proximity sensor was used to measure the deformation due to imposed stress and provided good repeatability. The stress-strain behavior of the bread obtained was nonlinearly within applied stress level(0.376 to 0.779 kPa). Assuming bread is a viscoelastic material, the proximity sensor method has been found to be effective and sensitive to evaluate creep tests to obtain rheological properties of bread by application of Inokuchi's method. The hardware is easily assembled and can be stored compacted when not in use.

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