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PHYSICAL PROPERTY OF WATERMELON. COMPRESSIVE CHARACTERISTICS OF FLESH OF WATERMELON AT STATIC LOADING

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A b s t r a c t. It is difficult to measure the physical properties of agricultural products precisely. In this study, two displacements of the axial and the radial directions of cylindrical specimens of the flesh of watermelon were measured with non-contact displacement sensors at static loading. The two displacement sensors are of the optical-reflective type with a light emitting diode and a semiconductor laser diode. The outputs are analogue voltages in proportion to each displacement measured in units of 1 μm. The approximate dimensions of the specimens were 40 mm in diameter and 34mm in height, and the actual dimensions were measured automatically by the experimental device. The experiments were done by setting the axis of the cylindrical specimens vertically and by altering the static load on the specimens at 0.0098 N (equal to the stress about 7.8 Pa), 0.0196 N (15.6 Pa), 0.049 N (39 Pa), 0.098 N (78 Pa), 0.196 N (156 Pa), 0.490 N (390 Pa), 0.98 N (780 Pa) and 1.18 N (936 Pa) as the distributed loads, and 0.490 N, 0.98 N and 1.18 N as the concentrated loads. The results show that the two displacements are generated by the static-distributed load, and that the displacements return to the original condition when the load is in the range of under about 0.05 N and when it is removed. When the load value increases, the permanent strain remains.

K e y w o r d s: watermelon, physical properties, compressive characteristics

INTRODUCTION

It is important in Japan to select watermelons of uniform condition and to prevent burst or split of watermelon in transportation; therefore, skilled farmers select good watermelons by considering the tapping sound, vibration, and other factors. It seems that the vibrational and acoustic characteristics show the internal condition of watermelon. This study was made to determine these two characteristics of watermelon by tapping the watermelon by a non-injuring method, and measuring the elasticity of the whole fruit. If the watermelon is regarded as an elastic material, it seems that the vibrational and acoustic characteristics relate to the mechanical characteristics. The punching test is usually employed to clarify the elasticity of the fruits, but the test is done through the elastic and visco-elastic regions and until cells are crushed by a large deformation. Therefore it is thought that the result of the test does not represent the response of fruit under the purely elastic region. The object of this study is to clarify the characteristics of the very little deformation through little strain on fruits micromechanically. Especially, when it is thought that the fruit is a union of cells through which the force is transmitted, it is very important to analyse the response of fruits under very little deformation for clarifying their physical properties.

EXPERIMENTAL EQUIPMENT

A construction of the experimental devices is shown in Fig. 1. The experimental devices, which are a level, a power switch, a power indicator, connecting terminals, two sets of a sensing head and an amplifier, a base-plate, two vertical frames for the sensing head, and five supporting legs, are assembled on the L-shaped aluminium frame. The level and five supporting legs to keep the equipment horizontal are adjustable by screws at the bottom of the legs; the vertical position of the sensing head is therefore assured. The sensors detecting the axial and the radial displacements of the cylindrical specimen are of the optical-reflective type, each with a sensing head and an amplifier. The axial and radial displacements are detected by a LED type and a semiconductor laser diode type sensor, respectively. The two sensors measure simultaneously. The sensing head measuring the axial displacement is adjustable at intervals of 3 mm and preset at the most suitable position. The distance from the sensing head for the radial displacement to the base-plate is kept constant to detect the actual diameter of the specimen. The specifications of the sensors are shown in Table 1. The unit is 1 μm and the outputs are analogue voltages in proportion to each displacement. The power supply is DC 12 V. The measured data were recorded by a magnetic data recorder. The recorder has an analogue to digital converter using the pulse - coded - modulation (PCM) method and records on

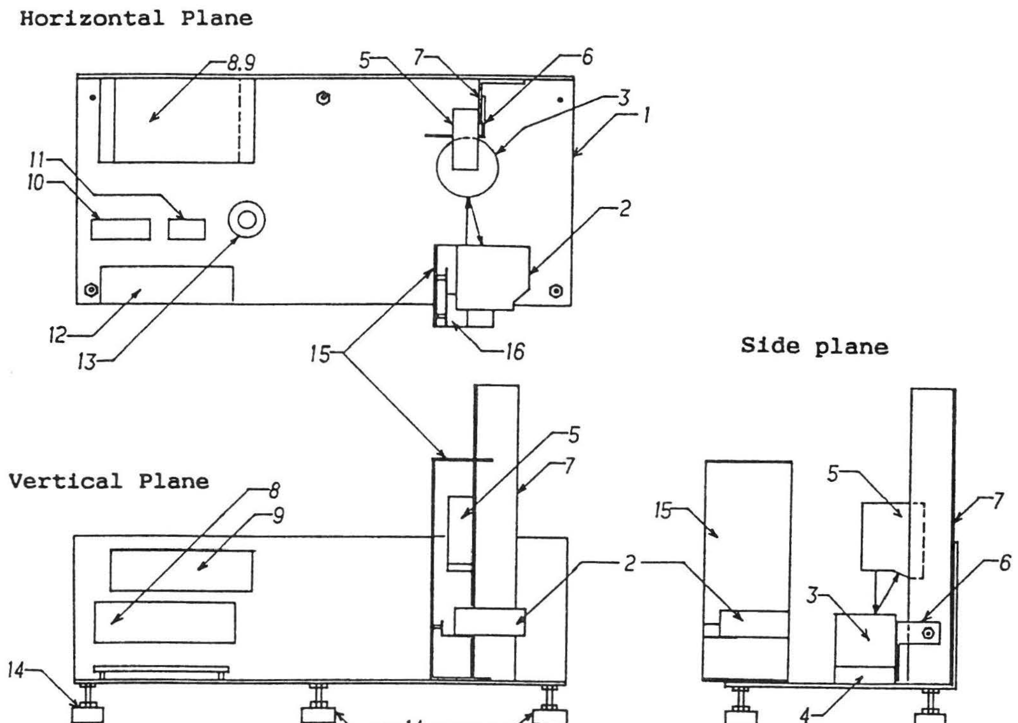

Fig. 1. Experimental devices. 1 - L-shaped aluminium frame, 2 - sensing head of laser displacement sensor, 3 - cylindrical specimen, 4 - spacer, 5 - sensing head of LED displacement sensor, 6 - base-plate, 7 - frame for LED displacement sensor, 8 - amplifier of LED displacement sensor, 9 - amplifier of laser displacement sensor, 10 - power switch, 11 - power indicator, 12 - terminals, 13 - level, 14 - five supporting legs, 15 - frame for laser displacement sensor, 16 - angle frame for laser displacement sensor.

Table 1. Specifications of the sensors

Parameter	Sensor detecting	
	axial displacement	radial displacement
Light source	LED (Light Emitting Diode) (colour: red [a visible ray])	Semiconductor laser diode (wave length: 780 nm) Maximum: 3 mW (Class 3b)
Diameter of spot	under 1.5 mm	1.0 mm x 2.0 mm
Reference distance	38 mm	100 mm
Measuring range	12 mm (far side) 8 mm (near side)	20 mm (far side) 20 mm (near side)
Linearity	1 % full scale	0.8 % full scale
Output voltage	-2 V (near) ~ 4 V (far)	-5 V ~ 5 V
Resolution	3 μm	10 μm
Frequency response	DC ~ 40 Hz	DC ~ 0.6 Hz
Brightness	under 6 000 lx	under 4 000 lx
Temperature	0 °C ~ +50 °C	0 °C ~ +50 °C
Relative humidity	35 % ~ 85 %	35 % ~ 85 %

a digital audio tape (DAT). The frequency response of the recorder is DC ~ 10 kHz. The measuring principle is based (founded) on the strength of materials (showing the relation between stress and strain). The cylindrical specimen with the approximate dimensions of 40 mm in diameter and 34 mm in height was used in the experiments.

EXPERIMENTAL METHOD

Outline of sample of watermelon

The samples were divided into four groups: unripe fruits, about two weeks before harvesting time; unripe, about one week before harvesting time; just ripened; and overripe, picked one week late. The basic physical properties, the mean diameter, weight, and the sugar content are shown in Table 2. These are the typical values of each group.

Compressing experiment

The compressing experiments at static loading were done by setting the axis of the cylindrical specimens vertically on the spacer and touching the base-plate. The specimens were cut out from the centre of watermelon. A thin and rigid plate made of bakelite, 56 x 47 mm and 0.5 mm thick, was placed on the specimen directly and weighted for the static load. The weight of the plate was 1.7 g and the various weights were 1, 2, 5, 10, 20, 50, 100, and 120 g. The experiments were done by altering the static load on the specimen at 0.0098 N (equal to the stress of about 7.8 Pa), 0.0196 N (15.6 Pa), 0.049 N (39 Pa), 0.098 N (78 Pa), 0.196 N (156 Pa), 0.490 N (390 Pa), 0.98 N (780 Pa), and 1.18 N (936 Pa) as the distributed loads, and 0.490 N, 0.98 N and 1.18 N, as the concentrated loads.

Table 2. Basic physical properties of watermelon

Group	1	2	2	4
Maturity	Unripe (two weeks early)	Unripe (one week early)	Just ripened	Overripe (one week late)
Mean horizontal diameter	174.5 mm	203.0 mm	270.0 mm	278.5 mm
Mean vertical diameter	161 mm	206 mm	259 mm	256 mm
Weight	2.283 kgf	4.608 kgf	10.28 kgf	9.133 kgf
Sugar content of flesh	5.9	6.8	10.4	12.6

RESULTS AND DISCUSSION

An example of experimental results is shown in Fig. 2. The sample of watermelon belongs to group 1 in Table 2. Fig. 2a shows the radial displacement and 2b the axial displacement caused by the distributed load. The radial displacement was measured at a height of 21.7 mm from the bottom of the specimen. These values show the relative displacement. Point A shows the condition at which only the thin rigid plate was set on the specimen. Point B is the result of loading a 1g weight, i.e., the static load on the specimen was 0.0098 N (7.8 Pa). The radial and axial displacements of point B were about 0.52 mm and 0.04 mm, respectively. When the load is removed (point C), both displacements return to their original conditions. Point D is the result of loading a 2 g weight (the static load was 0.0196 N (15.6 Pa)) and point E is of the same condition as that of point C. When the value of the loads increased to over 0.05 N (point F) for both displacements, the displacement did not return to the pre-load condition, and the permanent strain remained when the load was removed (point G). All other samples showed similar results.

It seems that the specimen responds elastically in the section between points B and E and plastically in the section beyond point F, and also under the concentrated loads. When the strain of the radial direction and the compressive strain are calculated from the values of point B in Fig. 2, the radial and compressive strains are 0.013 and 0.00118, respectively, and Poisson's ratio becomes about 11.05. This fact shows that the specimen is not an elastic material.

As the detecting height of the radial displacement is constant, the shape of the deformation of the axial direction is not clear.

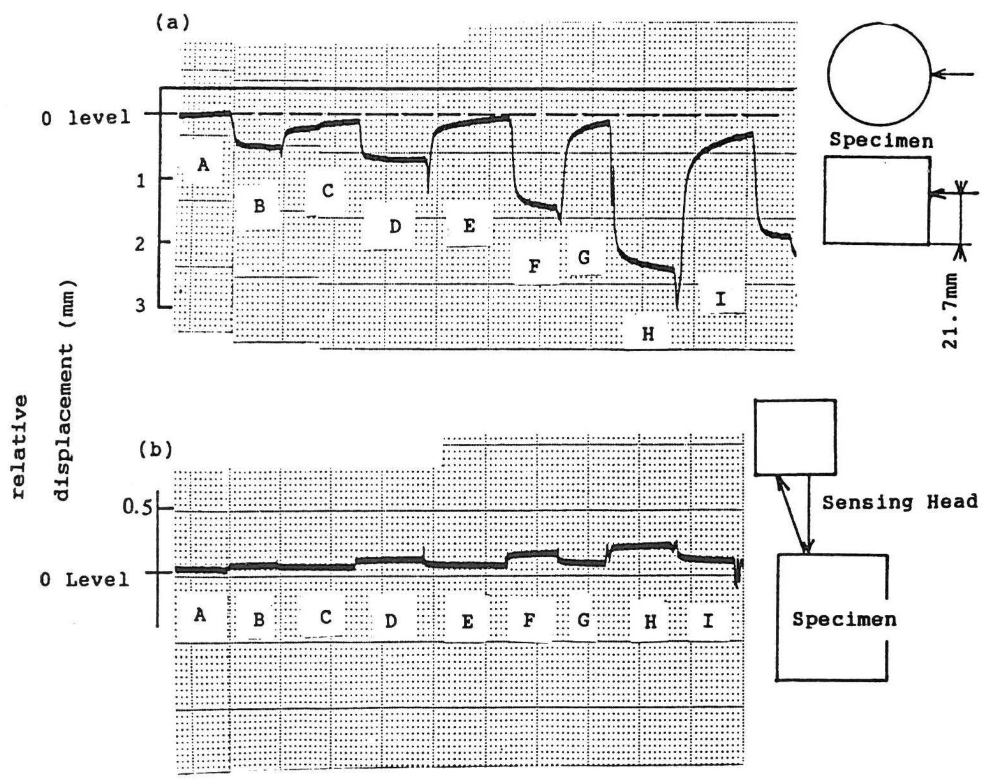

Fig. 2. Example of experimental results for radial (a) and axial (b) displacements.

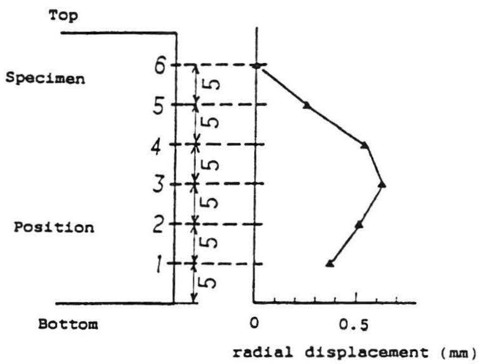

Fig. 3. Outline of deformation.

The shape of the deformation was also measured by changing the detecting height of the radial displacement at 5 mm intervals (Fig. 3). The top, the bottom, and the far sides of the specimen against the radial displacement sensing head were restricted by the thin rigid plate and the spacer and the base-plate in the present experiment. The outline of the deformation was barrel-like as shown in Fig. 3. The deformation by the weight of the specimen itself needs to be considered. Each value of the radial displacement along the axis of the cylindrical specimen, i.e., the shape of deformation, differs in relation to the maturity, the sampling position of the flesh of watermelon, the condition of the specimen, and other factors. The results of the concentrated load were similar to those of the distributed loads.

CONCLUSION

The compressive characteristics of the flesh of watermelon at static load have been clarified from the experimental results. It is found that the flesh of watermelon is not an elastic material because the radial strain is larger than the compressive strain, and Poisson's ratio is over 1. Analysis of the micro cell mechanics is need to clarify these phenomena, because fruits and other plants are the union of micro cells, and it may be possible to correlate the vibrational and acoustic characteristics with the compressive characteristics by analysing the micro cell mechanics of agricultural products.

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