ZESZYTY PROBLEMOWE POSTĘPÓW NAUK ROLNICZYCH 1978 z. 203

A MECHANICAL MODEL OF FAILURE

Ferenc Kaifás

INTRODUCTION, OBJECTIVES

Agricultural products, when investigated from the mechanical point of view, can be considered to be nearly spherical or ellipsoid in form. From among their elements, skin and flesh contain 35 to 45 per cent solid matter. Depending on the duration of ripening and storing, the cell cavities also contain an incompressible fluid and 15 to 25 per cent gaseous matter, therefore they must be considered to be structures. By the influence of skin deformation of a certain degree harmful biochemical processes arise in these structures. It is just for this reason that a clarification of the relationship between biological changes and mechanical strains is important. Crops in their natural state possess geometrical symmetry and internal equilibrium. Mechanical strain causes local and volumetric deformation respectively, and after a time it leads to a rearrangement of internal stresses. When the biological stress limit is exceeded, these phenomena first cause breakage between the cells, and then on the skin of the crops. The object of this study is to determine the mechanical model of the processes of crop failure as they take place in space and time.

METHODS OF INVESTIGATION

In order to facilitate the setting up of the model, a few simplifying assumptions have to be made:

a) It is assumed, that the triaxial stress state of the crop can be produced as a superposition of three uniaxial stress states.

b) As experience shows, the behaviour of skin is wonlinear even with slight deformations. The relationship of load and deformation, however, was shown by measurement to be independent of time. Thus the characteristic of the skin material was approximated by a second-degree parabola.

$$\sigma_1 = E_1\varepsilon_1 - E_1\varepsilon_1^2\beta_1, \tag{1}$$

where E_1 and β_1 are constant. The breaking strength of the skin can be calculated from the relationship

$$\sigma_{1\max} = \frac{E_1}{4\,\beta_1}, \tag{2}$$

c) The flesh is in a transition state between the solid and liquid state. Its properties may be described by what is known as the Kelvin model, which is composed of a non-linear elastic and a viscose element in parallel connection.

The skin and flesh of crops interpenetrate, and this fact must also be expressed in constructing the model. Section "a" in Figure 1 shows the construction of a three-element model. Experiments will determine, whether the model comprising the non-linear elastic member is to be considered a real law of material. Let us follow theoretically the deformation

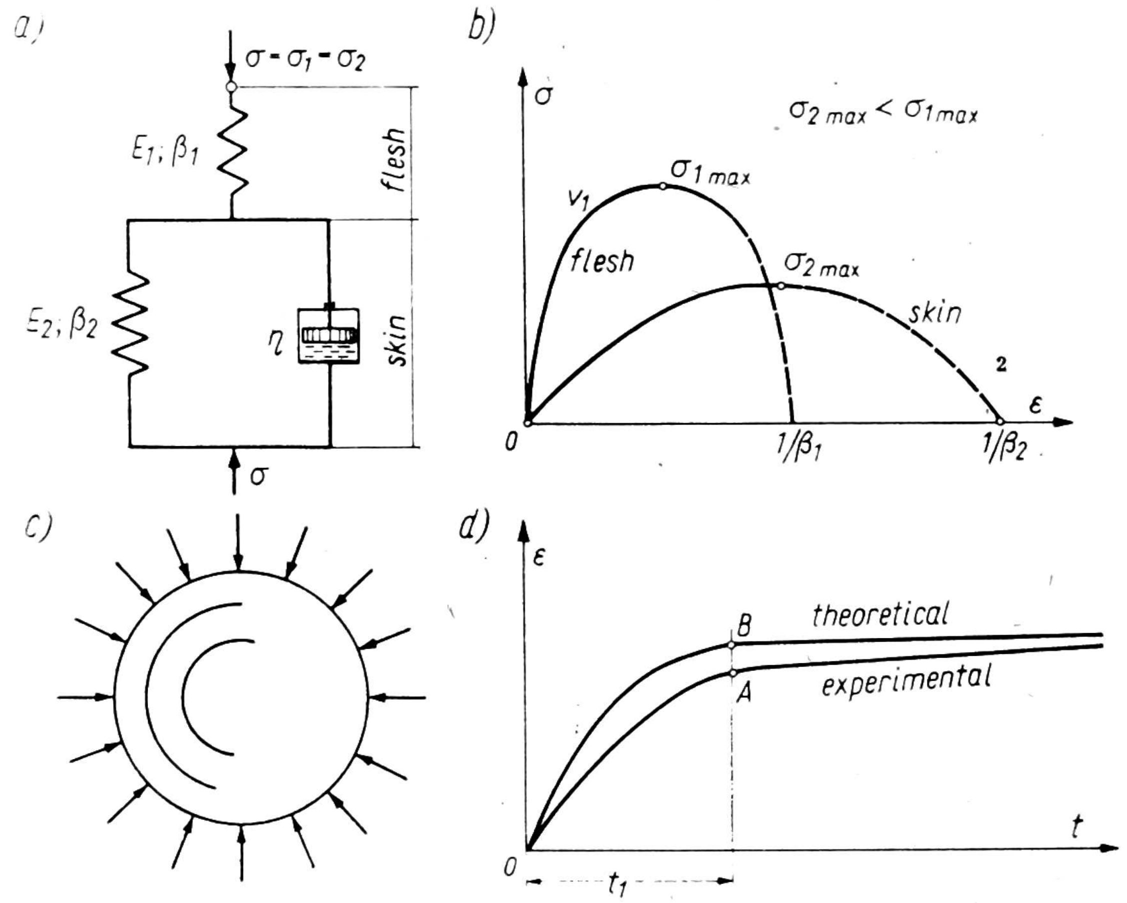

Fig. 1.

of the former model as plotted against time. Let the model be loaded by the constant breaking stress $\sigma_{2\max}$ characteristic of its flesh. The time t_1 of loading should be shorter than the time T of relaxation. In this case, the time-dependent deformation of the Kelvin body is expressed by the following formula.

$$\sigma_2 = E_2\varepsilon_2 - E_2\varepsilon_2^2\beta_2 + \eta\dot{\varepsilon}_2. \tag{3}$$

By means of a minor transformation the RICATTI differential equation is obtained.

$$\dot{\varepsilon}_2 - \frac{E_2\,\beta_2}{\eta}\,\varepsilon_2^2 + \frac{E_2}{\eta}\,\varepsilon_2 = \frac{\sigma_2}{\eta}. \tag{4}$$

Using the function transformation $\varepsilon_2 = -\frac{\eta}{E_2}\frac{\dot{Z}}{\beta_2 Z}$ the differential equation (4) can be changed into the second-order homogeneous linear differential equation

$$\ddot{Z} + \frac{E_2}{\eta}\dot{Z} + \frac{E_2\,\beta_2\,\sigma_2}{\eta^2}Z = 0. \tag{5}$$

The characteristic equation is:

$$r^2 + \frac{E_2}{\eta}r + \frac{E_2\,\beta_2\,\sigma_2}{\eta^2} = 0,$$

the solution of which, using the partial model load

$$\sigma_{2\max} = \frac{E_2}{4\,\beta_2} \qquad \sigma_{2\max} = \sigma_2. \tag{6}$$

$$r_{12} = -\frac{E_2}{2\,\eta}$$

From among general solutions the case $r_1 = r_2 = r$ will be studied more in detail. Then

$$Z = c_1 e^{r\cdot t} + c_2 t e^{r\cdot t} \tag{7}$$

that is:

$$\varepsilon_2(t) = \frac{1}{2\,\beta_2}\frac{t}{\left(\frac{2\eta}{E_2} + t\right)}, \tag{8}$$

the formula expresses the deformation of flesh as plotted against time.

A description of the behaviour of crops towards loadings necessitates studying the deformation of skin as well.

$$\sigma_1 = E_1\varepsilon_1 - E_1\varepsilon_1{}^2\beta_1. \tag{9}$$

Using the term E_1 as presented under (2), and having ordered the equation

$$\varepsilon_{1(t)} = \frac{1}{2\beta_1}\left[1-\sqrt{1-\frac{\sigma_1}{\sigma_{1max}}}\right], \tag{10}$$

the sum of partial deformations gives the total deformation of the model.

$$\varepsilon(t) = \frac{1}{2\beta_2}\frac{t}{\left(\frac{2\eta}{E_2}+t\right)} + \frac{1}{2\beta_1}\left[1-\sqrt{1-\frac{\sigma_1}{\sigma_{1max}}}\right]. \tag{11}$$

Equation (11) gives the creep curve of the crop with the $\sigma_{1\,max}$ constant load. Laboratory tests were made in order to check the theoretical results. In these tests crops in their natural state were loaded hydrostatically. It is a well-known fact that load causes the volume of the crop to change. Volumetric change is in a functional relationship with specific elongation and the mechanical properties of crops [1]

$$\frac{\Delta V}{V} f(\varepsilon(t). \tag{12}$$

The validity of the model was verified by comparing the calculated and the measured creep curves. (Section "d" in Figure 1.).

RESULTS

Farm crops are complex biological systems. There is no uniform method available in international literature for characterizing the processes of mechanical failure in them [2, 3].

The model presented here serves to give an approximate characterization of the process of failure. With the properties of the crop known, it is suitable to provide a more precise clarification of the crop-machine relationship than was possible earlier.

REFERENCES

1. Sharma Mg., Mohsenin N. N.: Mechanics of Deformation of a Fruit Subjected to hydrostatic pressure. Journal of Agricultural Engineering Research 1970. No. 1. 65—74.
2. Miles John A., Gerald E. Rehkugler: A failure criterion for Apple flesh. Transactions of the ASAE 1973. 1148—1153.
3. Hamann D. D.: Dynamic Mechanical Properties of Apple Fruit Wlesh. Transactions of the ASAE 1969. No. 2. 170—174.

F. Kaifás

MODEL MECHANICZNY OPISUJĄCY USZKODZENIA PŁODÓW ROLNYCH

Streszczenie

Płody rolne są żywymi biologicznymi organizmami. Podczas drobnych uszkodzeń w ich powłokach zachodzą niepożądane procesy chemiczne. Celem badań było ustalenie związku między zmianami biologicznymi a mechanicznym oddziaływaniem na płody rolne.

Referat podsumowuje wyniki przeprowadzonych w tej dziedzinie prac. Na podstawie doświadczeń przeprowadzonych na płodach w stanie normalnym określono budowę modeli mechanicznych.

Model składa się z dwóch nieliniowych sprężystych elementów i jednego elementu łączącego, przy czym jeden nieliniowy i jeden łączący element są włączone równolegle. Model był zbadany w sposób teoretyczny przy stałym obciążeniu. Płody poddawano obciążeniom hydrostatycznym w warunkach laboratoryjnych. Wyniki pomiarów przytoczono w referacie.

Ф. Каифаш

МЕХАНИЧЕСКАЯ МОДЕЛЬ ДЛЯ ОПИСАНИЯ ПОВРЕЖДАЕМОСТИ СЕЛЬСКОХОЗЯЙСТВЕННЫХ МАТЕРИАЛОВ

Резюме

Сельскохозяйственные продукты — это живые биологические организмы. При малом повреждении их оболочки происходят нежелательные химические процессы. Цель наших исследований — установление связи между биологическими изменениями и механическими воздействиями на плоды.

Доклад суммирует результаты проведенной в этой области работы. На основании опытов, проведенных на плодах в нормальном состоянии, определяется построение механических моделей после изменения механических воздействий во времени.

Модель состоит из двух нелинейных упругих элементов и одного связного, причем один нелинейный и связный элементы включаются параллельно. Модель была исследования теоретическим путем, при устойчивой нагрузке. Продукты подвергались гидростатической нагрузке в лабораторных условиях. Результаты измерений изложены в докладе.

Address of the author

Doc. Dr Ferenc Kaifás,
Agricultural University, 2103 Gödöllö, Hungary