STATIC AND DYNAMIC COMPRESSIVE TESTING INSTRUMENT FOR BIOLOGICAL MATERIALS

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Abstract

During in our early research work (OTKA-881) an experimental testing instrument was elaborated for static and dynamical compressive investigations for some agricultural materials, first of all fruits and tubercular roots. The need has arisen for construction of a computer-controlled instrument, which is suitable to make serial measurements, and gives the possibility of the regular calibration process. The instrument in its present implementation is capable for making compressive testing with usual size loading-stick with constant, linear slope and cosine wave force-time functions, in single or multiple sweep mode. The force is generated by a PC controlled servo system and the deformation is measured by a laser-sensor. The system has a PC based data logger in it.

As an application of the testing machine the article describes the investigation of mechanical properties of paprika. The culinary paprika has an important role in Hungary not only in production, but in the consumption, too. During hand picking and mainly in case of automatic picking and expanding machinery packaging i.e. in crop handling the paprika is loaded by many mechanical influences. If the mechanical load remains below a critical level then there is no bruise or the bruise can regenerate. In other case above a critical level an irreversible bruise occurs and so the quality decreases with a considerable degree. A possibility of the analysis based on the characteristics of the testing instrument. A simple measuring method is given to find the limit of the mechanical load which can bruise the paprika. The investigation was supported by Hungarian Scientific Research Fund (OTKA T 46917).

Keywords

testing machine, mechanical properties, biological materials

Introduction

The approximate and macroscopic description of agricultural or biological materials is difficult owning to the complex and time-dependence structure. The gathering, food processing, the transport and the storage takes place in time and the material is under stochastic load. The time-dependent deformation, creep and relaxation of the material in function of internal force, deformation and time belongs to the rheology. The agricultural and biological materials have behaviour similar that of solids and liquids, too. These are viscoelastic materials. The description of biological material can be done with rheological models. The most simple models consist of spring(s) and dashpot(s). More complicated models can be constructed with parallel and serial connections of the basic elements, like Maxwell, Kelvin, Poynting-Thomson and Burgers models (Steffe, 1996).

The culinary paprika has an important role in Hungarian market. The paprika producers try to find their proper positions not only in domestic market, but in European Union, too. The producers are forced by the sharp competition to do everything for the best adaptation to the requirements of the market. Excellent quality must be produced, assorted and packed economically at a given shipping schedule in according to the demand not only of the customer, but the EU regulation itself, too. These requirements are met less and less with tight and occasional man-power, the utilization of machine work in case of sorting and packaging gets urgent. During the machine manipulation the bruise proof operation can be realized, if the mechanical load is in the range of bruise proof values. There are several articles about the technical side of the growing e.g. Dimény et al. (2004); Fekete et al. (2005). Fenyvesi (2004) summarized his bruise investigations of agricultural materials in his recently published book.

Methods and materials

Instrument

During our research work many years ago an experimental testing instrument was elaborated for static and dynamical compressive investigations for some agricultural materials, first of all fruits and tubercular roots to determine the viscoelastic behaviour (Fenyvesi et al. 1989). That instrument was a simple and hard to handle. There are many kinds of biological materials and plastics in the agriculture and food industry during handling, manipulating, packing and processing that's why the need has arisen for construction of a new, improved computer-controlled instrument, which is not simply a single purpose rheometer, but, if it is possible, an universal one, which is suitable to perform lots of functions. In most cases the conventional testing machines can generate a static load or low rate deformation. The oscillatory testing instruments can generate only periodical load. Our instrument can realize the „bridge" between the two methods.

During experiments the elements of the rheological model can be determined with measuring the force-deformation function or its inverse function. In many agricultural applications the compressive force function is applied with an A cross-section loading pin and the deformation is recorded at the same time (Fig.1.).

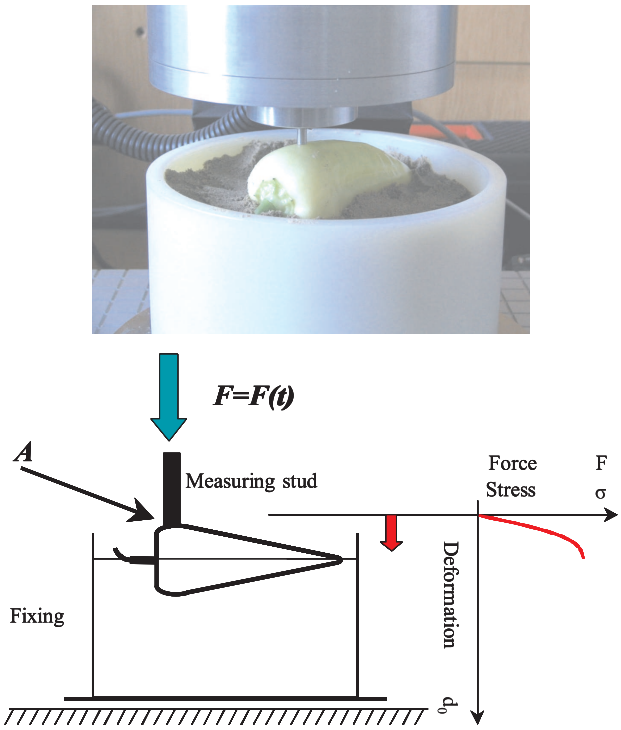

Figure 1. The loading of the paprika surface with measuring pin

We have two possibilities: 1. during known deformation-time function we measure the reacting compressive force, or 2. applying a known compressive load we measure and record the deformation. The widely used screw-bolt testing machines can work only at a low deformation-rate and the F(t) reaction force as a response function can be measured. High deformation rate can be realised only with difficulties. During loading pin tests of many agricultural materials, fruits and tubercular roots only cca. 10 N compressive force is needed. A linear guidance moving coil in static magnetic field, a kind of linear motor is a proper solution for generating a compressive (or tensile) force with a reasonable stroke. The generated force-time function F(t) can be controlled by the electric current. In electronic circuit the required current-time function can be generated and so we can generate a required F(t) function. During acting F(t) force function the Δl(t) deformation-time function can be recorded. From the stimulating F(t) and Δl(t) response functions the elements of the rheological model can be calculated.

The project is still actual. The progression of electronic and sensor technology together with computer technology gave the possibility to design and build a new more usable testing instrument which can be calibrated easily. The block diagram of the instrument is on the Fig. 2.

The instrument, the Dynamical Material Tester (DyMaTest) in its present implementation is capable for making linear compressive testing with usual size loading pin with constant (force step), linear slope (linear up/down loading) and cosine-wave (oscillatory testing) force-time functions in single or multiple sweep mode and measuring the deformation of the material at the same time. The force is generated by a PC controlled servo system and the deformation is sensed by a laser sensor. The system has a PC based data logger in it. The application range of testing with the system is limited by the mechanical and electromechanical properties of the instrument. The maximal load is 15 N, the maximal deformation is cca. 10 mm and the electromechanical cut-off frequency is 200 Hz. The loading pin is changeable (∅ 4 mm, ∅ 5 mm, ∅ 6 mm) and optionally other small size loading forms (knife, needle, etc…) can be fixed. The whole instrument and the measuring set-up can be seen on Fig. 3.

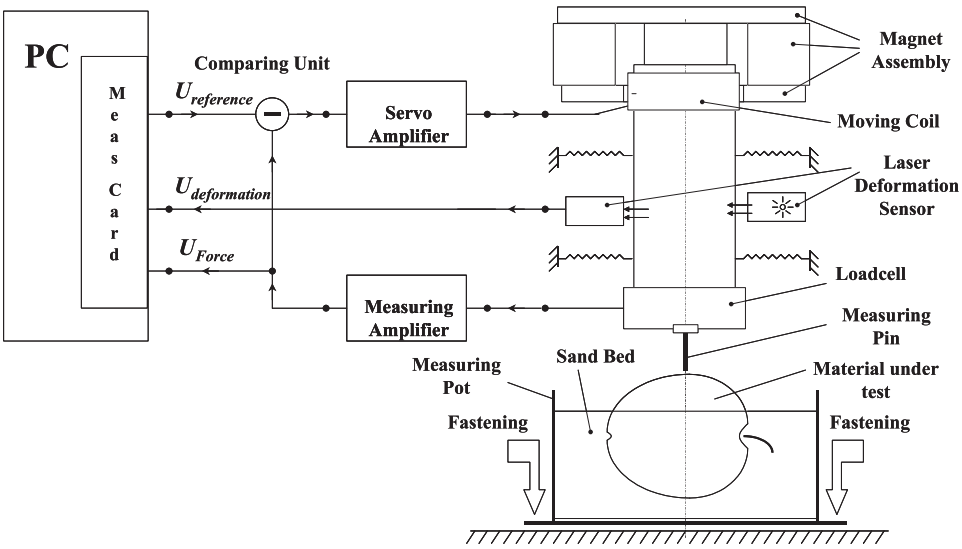

Figure 2. Block diagram of the instrument

Figure 3. The DyMaTest measuring set-up

Paprika investigations

Machine manipulation has a lot of mechanical influences on the culinary paprika. Reducing the mechanical load to the paprika the probability of the bruise can go down, but together with it the price of the machine and the duration of the manipulation time increases very much. There is no manipulation without mechanical load applied to the surface of the paprika. That's why we try to estimate the critical value of the compressive load. The existence of the bruise can be observed correctly only a few days later with the local appearance of the colour change. So the investigation needs a lot of time. Usually the surface of the biological material is compressed in a testing machine (e.g. Zwick, Instron or Loyd), the load value is recorded and the bruise point can be determined. The mechanical testing machines can press a measuring pin or a special forming pressing surface into the material with low adjustable deforming rate. During the deformation the force can be measured with load cell, and so the deformation – force diagram is recorded. The investigation can carry out with quick and repetitive load with DyMaTest dynamical and programmable testing machine (Petróczki, 2005, 2006) shown at the Fig. 1. In DyMaTest in according to the principle of the instrument the shape of the compressive load can be set and not the deformation rate like the conventional mechanical testing machine. So the deformation is the function of the load here.

After the study of the references above and the preliminary considerations we can say, that at a low compressive load the behaviour of the surface is elastic and not categorically linear. Together with the increase of the compressive force the pressure of the liquid inside the cell increases as well, the load of the cell wall increases, deformation occurs and the force-deformation function is continuous. In case of the bruise a kind of irreversible effect e.g. cell wall tear takes place, which modifies suddenly the slope of the function. So we analyse the step of derivative of the deformation-time function. The force which causes this step is named critical or end force. It means, that below this force there is no bruise yet.

The measurements was carried out at the middle part and at the biggest diameter of the paprika so, that the measuring pin load plane was parallel with the surface of the paprika. The paprika was supported by the sand-bed on a large surface. The diameter of the measuring pin was ø 5 mm. The load function was programmed so, that the compressive force increased linearly up to the maximal value during 1,2 second, next decreased for the same time up to the zero load. Our test lasted for three load-cycles, but only the first rising slope was used for the calculations. The preload was 0,1 N. Two kinds of measurement was carried out with 5 N and 10 N maximal forces.

During investigations we have found no step of deformation in case of 5 N maximal value as can be seen on a „typical" diagram of the Fig. 4.

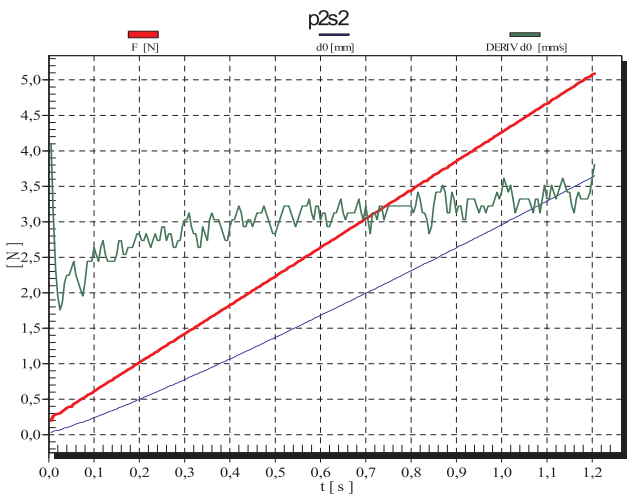

Figure 4. The increasing compressive force (F) from 0 N up to 5 N, the deformation of the surface (d_0) and its derivative with respect to time (DERIV d_0)

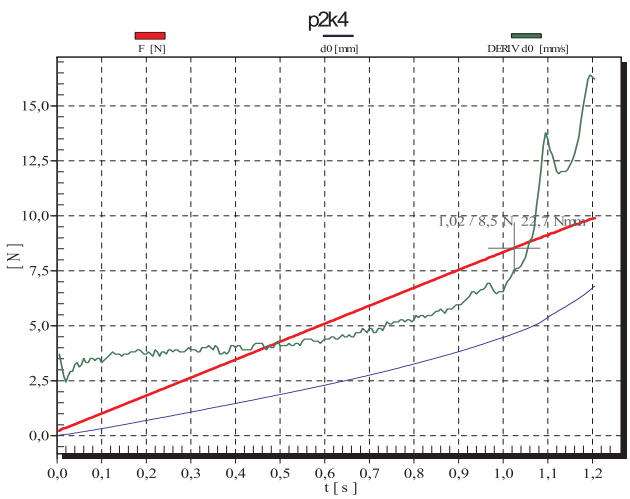

Figure 5. Diagram of a „visible" bruise. The bruise started at cca. 8,5 N

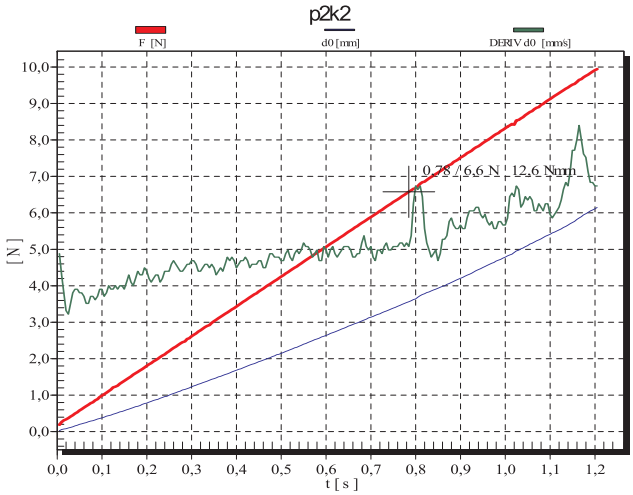

Figure 6. Diagram of a „non visible", but "probable bruise". The bruise occurred at 6,6 N

The compressive force increased up to 10 N in Fig. 5. The deformation (d_0) increased monotonic up to 8,5 N (until 1,02 s) and next a discontinuity appeared on the curve. The whole process can be observed more clearly on the derivative of the deformation, where can be seen, that there is an irregularity already at 0,96 s, but we can say explicitly, that the bruise starts at 8,5 N. This diagram as an example was presented, because the bruise was visible to the naked eye, too. Fig. 6. shows an imperceptible to the eye, but a probable bruise time diagram.

Results

DyMaTest specification is given in Table 1. During investigations with DyMaTest the possibility is given to determine not only the static, but the dynamical viscoelasic properties of agricultural and biological materials and in some cases plastics. Because of the software control of the whole instrument the system includes the capability to generate a stochastic load onto the material under test and the whole process can be reproduced from the point of view of mechanics in the laboratory.

Table 1. DyMaTest specification

Max. compressive load	15 N
Force transducer	low mass special strain gage transducer
Load shape	single or multiple sweep
Force-time functions of the load	Constant load Linear up/down load Sinusoidal load Square wave load (Random or pseudorandom load)
Deformation	Max. 10 mm
Deformation sensor	OMRON ZX-LT typ. Smart Parallel Laser Through Beam Sensor
Deformation resolution	3 µm
System bandwidth (-3 dB)	0-200 Hz
Measuring (loading) pin diameter	Ř 4 mm, Ř 5 mm, Ř 6 mm

An example of the application of the instrument was given in the field of bruise investigations of paprika. Neither visible nor invisible, but probable bruise during our investigations below 5 N maximal load was recognised. The number of repetition at max. 10 N load was 16, the number of the visible and the „probable bruises" was 10 from it. In remaining 6 cases there was no bruise during tests at all. The critical value of the compressive force is 6,4 N. It means, that the load below it didn't cause bruise in our investigations.

Conclusions

The DyMaTest is efficient instrument during compressive testing of biological materials and gives the possibility to investigate the fine structure of the deformation. In the example above not only the critical force of the visible bruise, but the value of the force which causes a probable bruise can be determined from the measurements with linearly increasing compressive force generated by the instrument. Next time a new investigation is recommended to determine whether the probable bruise comes true or not. The simplest method is to do that to carry out the investigation of getting brown of the pressed surface after a few days. Measurements was done at the peak part of the paprika and similar effect can be observed, but there is no possibility enter into details because of the limited length of the article and more complexity of the problem.

Acknowledgements

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