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SURFACE PRESSURE DISTRIBUTIONS FOR PEARS AT A CONSTANT VALUE OF LOAD

Małgorzata MŁOTEK, Roman STOPA, Piotr KOMARNICKI, Daniel SZYJEWICZ, Łukasz KUTA

University of Environmental and Life Sciences in Wrocław, Poland, The Faculty of Life Sciences and Technology, Institute of Agricultural Engineering, Street: Chełmońskiego Number: 37/41, Zip Code: 51–630 Wrocław, Poland, Phone: +4871 320 57 00; 320 57 01, E-mail: lukas.kuta@o2.pl,malgorzata.porczyk@up.wroc.pl

Corresponding author: lukas.kuta@o2.pl

Abstract

The paper presents the results of surface pressure measurements for pears subjected to creep testing. The study was conducted in the Laboratory of Agrophysics at the Agricultural Engineering Institute of Wrocław University of Environmental and Life Sciences. The load was applied using an Instron 5566 testing machine equipped with a strain gauge head of a measuring range up to 1 kN that allowed measuring the strength with an accuracy of 1 N, and the offset with an accuracy of 0.05 mm. The machine was controlled by a computer with BlueHill software which enabled the recording and analysis of test results. The head feed speed until it reached the predetermined value of preload was 1.8 mm·min^{-1}*. A sensor of the Tekscan system with number 5076 was fitted in the testing machine working area to enable continuous observation of the contact surface of the tested fruit with the working element of the testing machine as well as measurement of the surface pressures. The contours and distributions of surface pressures were determined at subsequent stages of the creep test. The maximum and the average values of surface pressures were found to be markedly reduced in the course of the test. The surface pressures distribution in the tested load range was found to take shape typical of contact cases of an elastic character, with the maximum value measured in the central contact zone. At the end of the test there was a slight equalization of pressure distribution on the contact surface of the fruit with the working element of the testing machine. The contact surface area of the maximum surface pressure values clearly increased. The measurements were carried out at three initial load values for 5 repetitions. After initial studies the measuring time at constant load was set at 1200 seconds.*

Key words: *compression, creep, pears, surface pressure, the time factor*

INTRODUCTION

The growing of pear dates back to Persia, from where they were taken to Rome. Pears reached Europe relatively late, around the 17th century. The largest plantations of the fruit can be found in Belgium and France. The latest data of the US Department of Agriculture (USDA) show that in the season of 2013/2014 the world's production of pears should amount to 21.87 million tones. In the season of 2014/2015 the European Union's production of pears amounted to 2.25 million tones, which put Europe in the second position after China, which is the largest producer of pears in the world. The largest European producers such as Italy, Spain, Belgium, Netherlands and Portugal grow 85% of pears produced in the European Union [7,11]. Pears take the fourth position among the most favoured fruit consumed in the European Union. Depending on buyers' preferences, they can choose from approximately 60 varieties of pears grown around the world. The fruit is elongated and oval. Depending on the variety, it has approximately 50-60kcal in 100g. The 100g portion of pear contains 84g of water. The fruit are rich in vitamins A, B1, B2, B6, C and PP. They contain potassium, magnesium, boron, iodine, sodium, calcium, phosphorus, and iron. Pears help reduce fever, have anti-inflammatory properties and the juice reduces blood pressure. The fruit is widely used in cosmetics as an additive for creams, masks, lotions and shampoos [11]. In order for the fruit to retain freshness and flavor for a long time, it is necessary to store them in appropriate conditions [10]. Picked from the trees, they continue to breathe, transpire and develop diseases. As a result of these factors the fruit deteriorate, their flesh softens, their peel wrinkles and they begin to decay. The ideal storage temperature of pears ranges from -1 to +1 °C. During transport, warehousing and storage the fruit is exposed to mechanical damage, which can lower its quality and bring loss for growers and exporters. For this purpose a study was carried out by A.F. Bollen [4] and G.L. Barchi [1]. The reduction of loss in the area of export and production translates to higher profitability of production [9]. This problem has been dealt with by Berardinelli A. et al [7], who searched for the varieties that would be the most resistant to damage during transport and storage.

The influence of the firmness of pears on the shelf life was studied by Garcia J.L. [5]. It turned out that discoloration is correlated with the size, ripeness and shelf life of fruit [3]. Peel discolouration due to long storage poses a serious problem in the post harvest processes. This phenomenon significantly reduces the value of fruit [8]. The mechanical properties of pears were also studied by [3] and [6]. It turned out that pears exhibited better mechanical properties immediately after harvest and they retained the properties until January if stored in a cold store in normal atmosphere (temperature -0.5°C); furthermore they could retain the properties even 2-3 months longer in the controlled atmosphere (CA) conditions.

The aim of the study was to:

-Draw contours and surface pressure distributions for "Lukasówka" pears under constant load and taking into account the time factor

-Determine surface pressure distributions in a selected cross-section in individual steps of the creep test.

MATERIALS AND METHODS

The study was conducted in the Laboratory of Agrophysics at the Institute of Agricultural Engineering at Wroclaw University of Environmental and Life Sciences. The Instron 5566 testing machine was used in the study. The unit was equipped with a strain gauge head of a measuring range up to 1 kN which allowed measuring the strength with an accuracy of 1 N, and the offset with an accuracy of 0.05 mm. The machine was controlled by a computer with BlueHill software that allowed the recording and analysis of test results. The head feed speed until it reached the predetermined value of preload was 1.8 mm·min^{-1}

The pears under study were the "Lukasówka" variety purchased in Trzebnica from a group of producers of fruits and vegetables ("Grupy Producentów Owoców i Warzyw Trzebnickie Sady Sp. z o.o."). Until purchase the pears had been stored in a cold store at a temperature of -1 to +1 in pallet-boxes. The purchased pears were selected for a similar shape, size and weight. The average weight of the surveyed fruit was 215gr. Maintaining a constant moisture content of the tested material was ensured throughout the study.

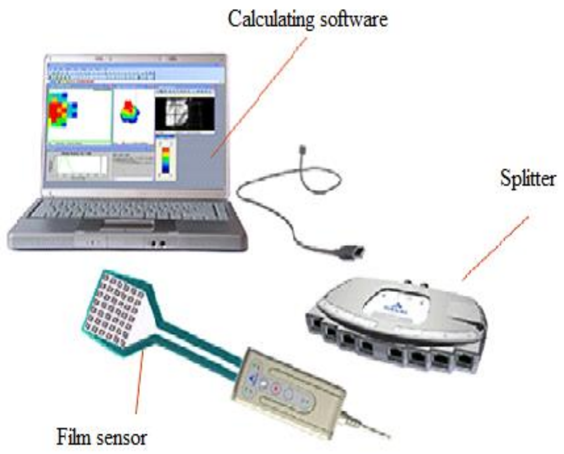

Fig. 1. Tekscan measuring system
Source: www.tekscan.com

The first measurements aimed to determine the load limits in the compression test. The breaking force value F_{max} was determined as the basis for calculating the value of the initial load in the creep test.

The surface pressures were measured with Tekscan system that enabled continuous observation of changes of the surface of contact between the tested fruit and the operating element of the Instron testing machine. The system consisted of a film

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sensor (pressure mapping sensor), fruit holder, splitter and computer software which allowed recording of the results of tests performed at a sampling frequency of approximately 1000Hz. It also allowed for subsequent analysis of the gathered data.

Table 1. Technical data of 5076 film sensor

Sensor dimensions		Longitudinal direction		Transversal direction		Number of sensels	Density of sensels
Height	Width	Spacing	Quantity	Spacing	Quantity	(pcs)	(pcs/cm^2)
(mm)	(mm)	(mm)	(pcs)	(mm)	(pcs)		
83.8	83.8	1.9	44	1.9	44	1936	27.6

Source: www.tekscan.com

The sensor that was used in the study, of the manufacturer's number 5076 (Figure 1, Table 1), consists of a set of two layers of parallel electrodes separated with a layer of polyester film. The electrode intersection points form sensels that enable to determine the value of the loading force and the surface area of contact between the tested fruit and the working element of the testing machine. During the test, the system recorded force values, surface pressure distribution and surface pressure contours as a function of time.

After initial studies the measuring time of 1200 seconds was assumed at a constant load ratio. Increasing the measuring time above 1200 seconds did not affect the nature of changes in surface pressure as a function of time.

As the samples for testing were prepared very carefully, the shape related error, as a systematic error, can be neglected.

The force measurement, the contact surface area measurement and the surface pressure values were determined using Tekscan system with the following parameters: system accuracy <± 4%, linearity error <± 3%, repeatability of the results <± 3.5%, hysteresis <± 4.5% and the drift <5%.

RESULTS AND DISCUSSIONS

Figure 2 shows an exemplary process of compressing the whole fruit until complete destruction. The compression test was replicated ten times at the measuring head speed of 1.8 mm min^{-1}. The received maximum force F_{max} for pears amounted to 782N and the corresponding displacement Δl_{max} amounted to 21.47mm. Based on the measurements, the initial sample load F_0 was determined together with the corresponding displacement of the sample loading element Δl_0.

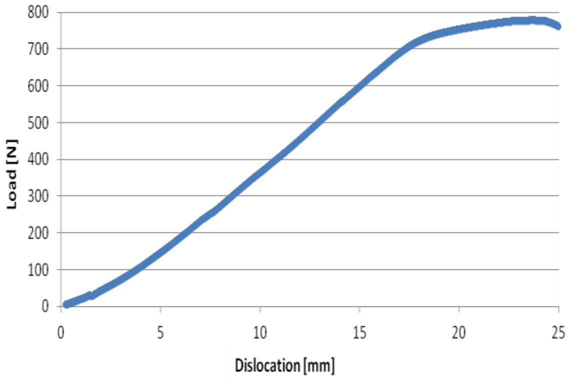


Fig. 2. Exemplary process of compressing the whole pear until complete destruction
Source: author's own research

Table 2 shows the parameters of the exemplary creep test on pears at the initial load equal to 30% of the breaking force F_{max} which was obtained in the process of compressing the whole fruit.

Table 2. Initial parameters of the process of compressing pears

Initial parameters	Initial loading	Initial displacement
30 % F_{max}	F_{030} =234.6N	Δl_{030} =6.44mm

Source: author's own research

Figure 3 shows the graph of the creep test for pears. The creep test started after 150 seconds from the start of measuring, after achieving the initial loading of F_{030} =234.6N.

Figure 4 shows the course of changes in mean surface pressures during the creep test on pears in 1200 seconds.

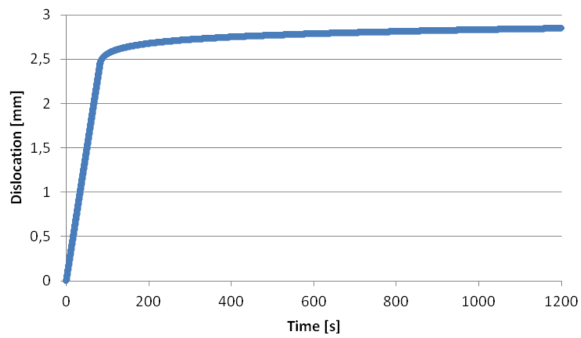


Fig. 3. The progress of the creep process
Source: author's own research

At the start of the test, after achieving the initial load F_{030} (at time t_0 = 180 sec.) the average surface pressure was p=0.429MPa, and at the end of the test (at t = 1200 sec.) it was reduced to p=0.392MPa. This means that the surface pressure decreased throughout the test at the rate of $3.6\cdot10^{-5}$ $MPa\cdot s^{-1}$. The biggest drop in pressure values was recorded in the first phase of the creep test (until t_1 = 500 sec.) and it progressed at the rate of $7.0\cdot10^{-5}$ $MPa\cdot s^{-1}$ to then decrease to a value of $2.6\cdot10^{-5}$ $MPa\cdot s^{-1}$.

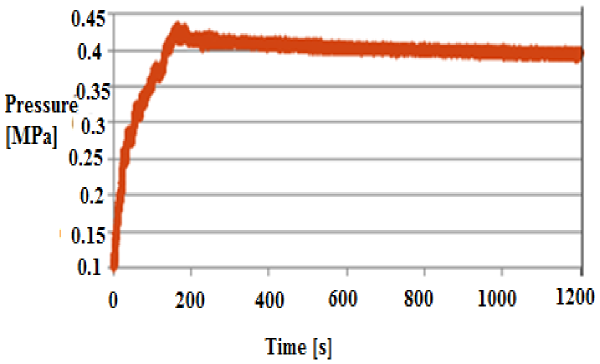


Fig. 4. Changes to the average values of surface pressures during creep test
Source: author's own research

Slightly different progress of changes was observed in maximum surface pressure values during the creep test (Figure 5). At the start of the test, the average p_{max}= 0.638 MPa, and at the end of the test the value went down to p_{max}= 0.592 MPa at a rate of $4.5\cdot10^{-5}$ $MPa\cdot s^{-1}$. The highest rate of decrease of the pressure values was observed in the first phase of the test (until t_0 = 180 sec.) and it amounted to $11.8\cdot10^{-5}$ $MPa\cdot s^{-1}$, which was almost twice as much as in the case of average pressures. In the remaining part of the test the rate significantly decreased and amounted to $1.8\cdot10^{-5}$ $MPa\cdot s^{-1}$.

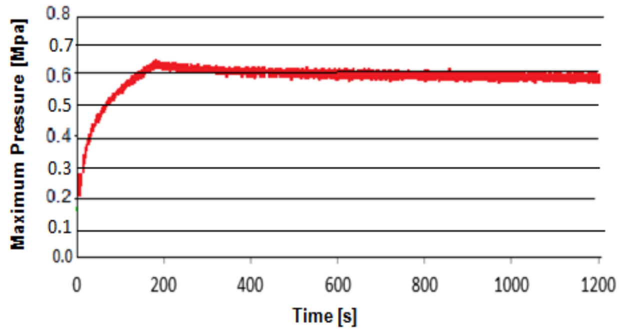
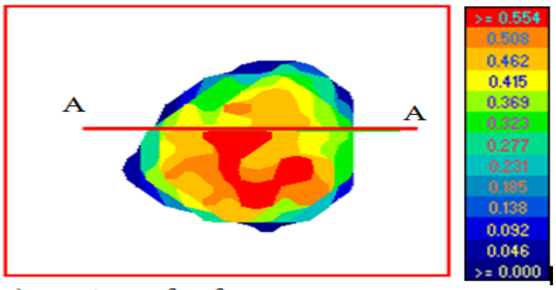
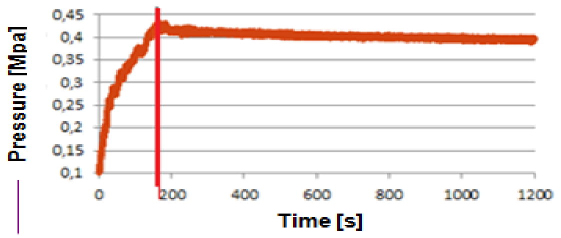


Fig. 5. Changes to the average values of surface pressures during creep test
Source: author's own research

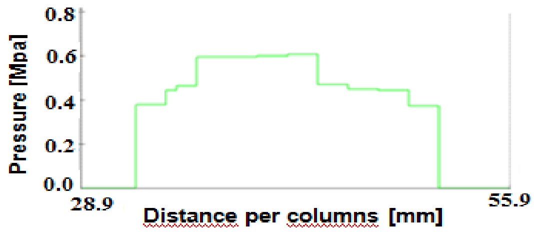
Figure 6 shows the contours and surface pressure distributions at the start of the test (at time t = 180 sec.).



a) Contours of surface pressures



b) Changes to the average values of surface pressures during creep test



c) Distribution of surface pressures in A-A cross-section

Fig. 6. Contours and distributions of the average values of surface pressures Δt=180 sec.
Source: author's own research

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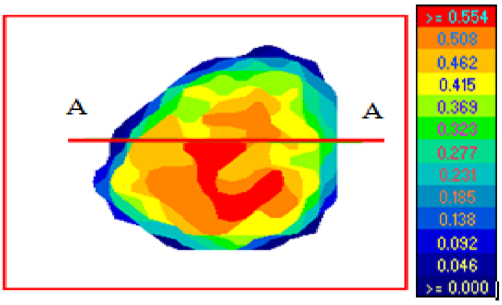
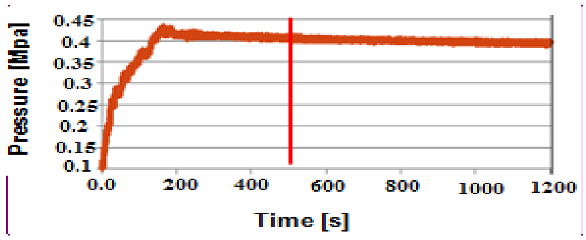
The maximum pressure values are identified in the vicinity of the central zone of the contact (Fig. 6a) and their distribution in the A-A cross-section with a characteristic peak in the middle part indicates the resilient nature of the contact. The maximum surface pressure values p_{max}=0.623MPa are recorded in the central contact zone, and the average values are p=0.429MPa. Distributions of surface pressures at the A+A cross-section (Fig. 6c) are of a regular shape with a distinct maximum at the contact point.

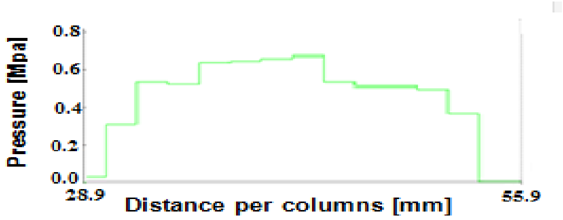
Figure 7 shows contours and surface pressure distributions at t=500 sec. from the start of the test. It was the period of the biggest decline in the value of the maximum surface pressures.



a) Contours of surface pressures



b) Changes to the average values of surface pressures during creep test

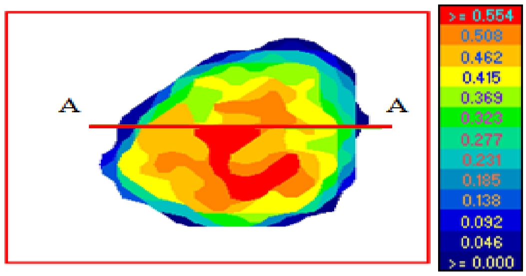


c) Distribution of surface pressures in A-A cross-section

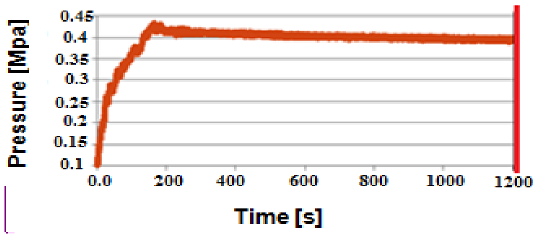
Fig. 7. Contours and distributions of the average values of surface pressures ka Δt=500 sec.
Source: author's own research

The compensation of pressures can be clearly seen on the surface of contact of a pear with the working element of the testing machine. The maximum surface pressure zone was enlarged (Fig.7a) and the distribution in the A-A cross-section (Fig.7c) flattened. The maximum surface pressure values near the center of the contact zone decreased to the level of p_{max}=0.604MPa, and the average surface pressure values decreased to p=0.407MPa.

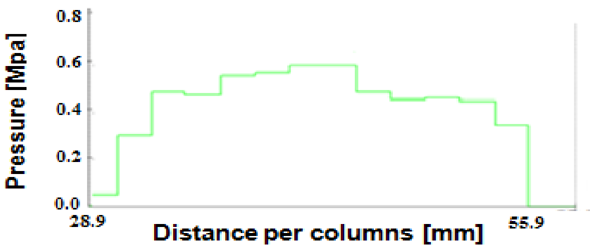
After 1200 sec., in the last phase of the creep test (Fig. 8), the contours and surface pressure distributions did not change significantly (Fig. 8a).



a) Contours of surface pressures



b) Changes to the values of surface pressures during creep test



c) Distribution of surface pressures in A-A cross-section

Fig. 8. Contours and distributions of the average values of surface pressures ka Δt=1200 sec.
Source: author's own research

The maximum values, still located in the central part of the contact of the fruit with a testing machine, decreased slightly (p_{max}=0.592MPa), as well as the average values (p=0.392MPa). Surface pressures distributions at the A-A cross-section (Fig. 8c) flattened, which indicates the compensation of pressure values across the entire contact surface. The form of surface pressure distribution in the A-A cross-section similar to an even function demonstrates a lack of destruction of the pear flesh. The contact surface is still of a resilient nature. The appearance of permanent deformations resulting from the destruction of the cellular structure of tissue would be revealed through the reduced surface pressure values in the central zone of the contact (Herold et al., 2001). As a result, the greatest pressure values would appear in border areas of the contact surface and the smallest in the central zone. The compensation of pressure values across the entire contact surface during the test is caused by migration of water in the intercellular spaces from the zones with the highest pressure value towards the zones where these pressure values are lower. The average pressure value decreased due to the increase of the contact surface area from $A=501mm^2$ at the beginning of the test to $A=584mm^2$ at the end.

CONCLUSIONS

The value of the average surface pressures throughout the entire creep test lasting 1200 seconds decreased from 0.429MPa to 0.392MPa. The value of the maximum surface pressures throughout the entire creep test lasting 1200 seconds decreased from 0.636MPa to 0.592MPa. The contact surface area throughout the entire creep test lasting 1200 seconds increased from $A=501mm^2$ at the beginning of the test to $A=584mm^2$ at the end. The distribution of surface pressures throughout the test for A-A cross-section forms a shape that is characteristic of contact items for resilient materials – with maximum values located in the central zone. The values of pressures across the entire contact surface of a pear and the working element of the testing machine clearly compensate after approximately 40% of the test duration time.

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