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BEHAVIOUR OF THE PEACH UNDER UNDERWATER SHOCK WAVE LOADING

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Abstract

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The paper concerns with the experimental and numerical study of the peach (*Red Haven*) at underwater shock wave loading. The behaviour of the peach skin as well as peach stone can be described in terms of elasticity. Following experiments have been performed: tensile testing of the skin (exocarp) specimens at constant elongation at strain rate 0.01 s^{-1}, compression test of the mesocarp specimens at different strain rates corresponding to quasi – static loading, compression test of the mesocarp specimens at the high rates of strain (about 1000 s^{-1}), and compression test of the whole peach stone at strain rate corresponding to quasi – static loading. The model of the peach has been suggested. The model is used for the numerical simulation, which was performed on the software LS DYNA 3D finite element code. Pressure wave propagation in the water has been studied and following quantities evaluated: pressure on the peach surface, displacement, and surface velocity. Two different models (Maxwell and Kelvin) have been used. The results of this simulation show some agreement with results of the observation (undamaged peach skin). The numerical simulation also gives an insight on the details of the loading, which was recently tested as a tool of fruit treatment. It has been shown that undewater shock wave treatment of peaches can lead to their softening.

peach, shock wave loading, numerical simulation

Shock wave is a pressure wave, which propagates in a medium, such as gas, liquid or solid, by changing its physical state rapidly. The shock wave propagates in a medium faster than the acoustic velocity, so called "super sonic velocity". Shock wave is a compression wave, and its pressure, temperature, and density behind the shock wave increases than that of the region ahead of it. In many cases, shock wave is accompanied with an expansion wave, so that it attenuates during the propagation, and finally the velocity becomes acoustic wave (Ando et al., 1999; Iyama, 2003).

Underwater shock wave is generated by means of underwater explosion of an explosive. Water is used as a medium for propagating the shock wave. An advantage of using water is that the adjustment for the intensity of its pressure value is easy by changing the traveling distance of the shock wave in water. This is why the controlled underwater shock waves are frequently used for food processing. It is also possible to prevent the heating effect using water. This effect can minimize the loss of nutrient component in the processed food. In some previous research see e.g. (Itoh, 2008), shock wave treatment of some foods containing water, such as apple, Japanese radish, and pineapple, leads to softening the food by maintaining their original shape. Without cutting the grate foods, juice was easily obtained by squeezing by hand. Also, the permeability of Japanese radish for seasoning was improved. In the case of making dry foods, such as coffee beans and green tea leaves, underwater shock treatment can make easier the powdering of these samples. It is obvious that effective use of this technology is conditioned by the research of this kind of loading. The research is mostly based on the numerical simulation of the shock wave effect. In order to perform such study some model of the peach mechanical behaviour is needed. This problem is solved in the presented paper.

MATERIAL AND METHODS

The peaches (*Red heaven*) were obtained from the orchards of the Department of post harvest technologies, Lednice, Mendel University of Agriculture and Forestry. Fruit were picked at the optimum harvest date (17/07/2007) for long term storage. In order to design the model of the mechanical behaviour of the peach it was necessary to study the mechanical behaviour of the main part of the peach. This behaviour is described in terms of the constitutive equation of the peach, which is a typical representative of „stone fruit“. The equation should describe the time dependent behaviour of the peach in broad spectrum of the strain rates including impact phenomena.

The influence of the strain rate has been monitored namely for the mesocarp specimens. The behaviour of the stone as well as the exocarp has been found to be independent on this factor.

The following experiments have been performed:

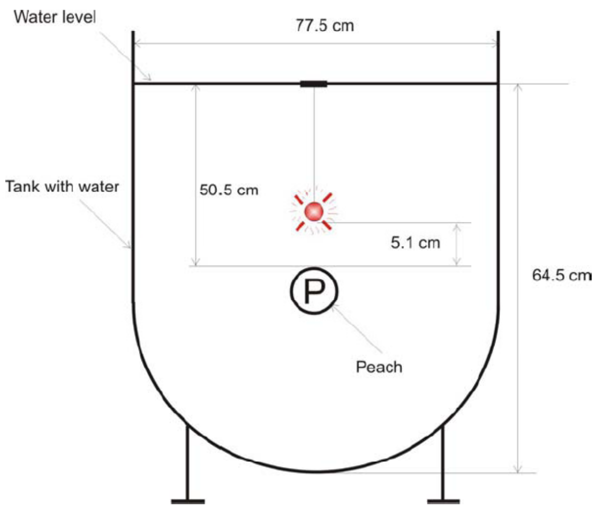
- Tensile testing of the skin (exocarp) specimens was performed at constant elongation (displacement control test) at strain rate about 0.01 s^{-1}. The aim of these experiments was the evaluation of elastic constants as well as the stress and strain at the fracture.
- Compression test of the mesocarp specimens at the different strain rates corresponding to the quasi – static loading.
- Compression test of the mesocarp specimens at the high rates of strain (about 1000 s^{-1}). The Hopkinson Split Pressure Bar Technique (HSPBT) has been used. This method is often used for testing of materials with low acoustic impedance like fruits, human tissues etc. (Chen at al., 1999; Sharma et al., 2002).
- Compression test of the whole peach stone at strain rate corresponding to the quasi – static loading.

The results of these experiments have been used for design of the constitutive equations of the three main parts of the peach.

The next group of the experiments has been focused on the underwater shock loading of the peach. The schematic of the used experimental arrangement is shown in the Fig. 1.

Special charge designed of PETN, aluminum void and steel ring have been used. Experiments have been carried out on the testing site at the Explosia company in Pardubice–Semtín.

The real experimental arrangement is shown in the Fig. 2.



1: *Schematic of the experimental set – up used for the underwater explosive loading of the peach*

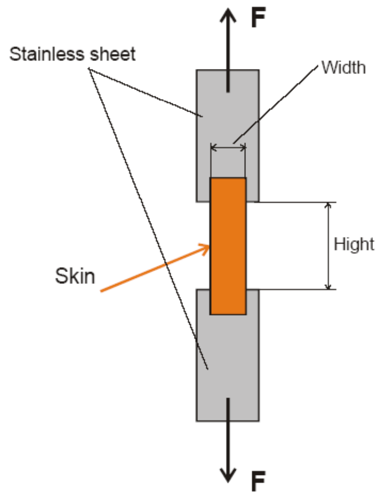
2: *a) Experimental arrangement before explosion* *b) Situation after the charge detonation*

RESULTS AND DISCUSSION

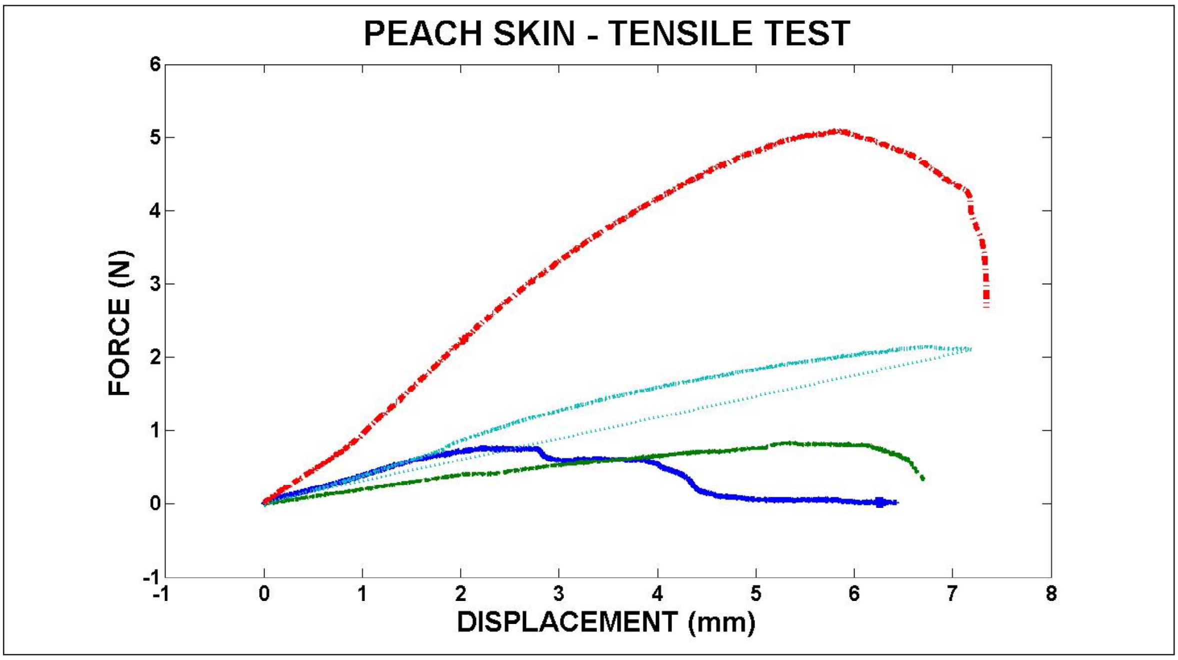
Tensile testing of the skin

The procedure of the tensile loading of the skin specimens is outlined in Fig. 3. Average width of the specimens was 18 mm, length 23 mm and thickness 0.3 mm. The strain rate was about 0.007 s^{-1}.

In Fig. 4, the dependence force – displacement record is shown. The obtained records have been converted to the stress – strain dependences. For the next evaluation the average values of stress and strain have been used. Experiments show that the skin behaves elastically with the Young modulus E=17.1 MPa. The stress at the fracture was found to be 5.3 MPa (average value). The Poisson ratio has been estimated as 0.35.



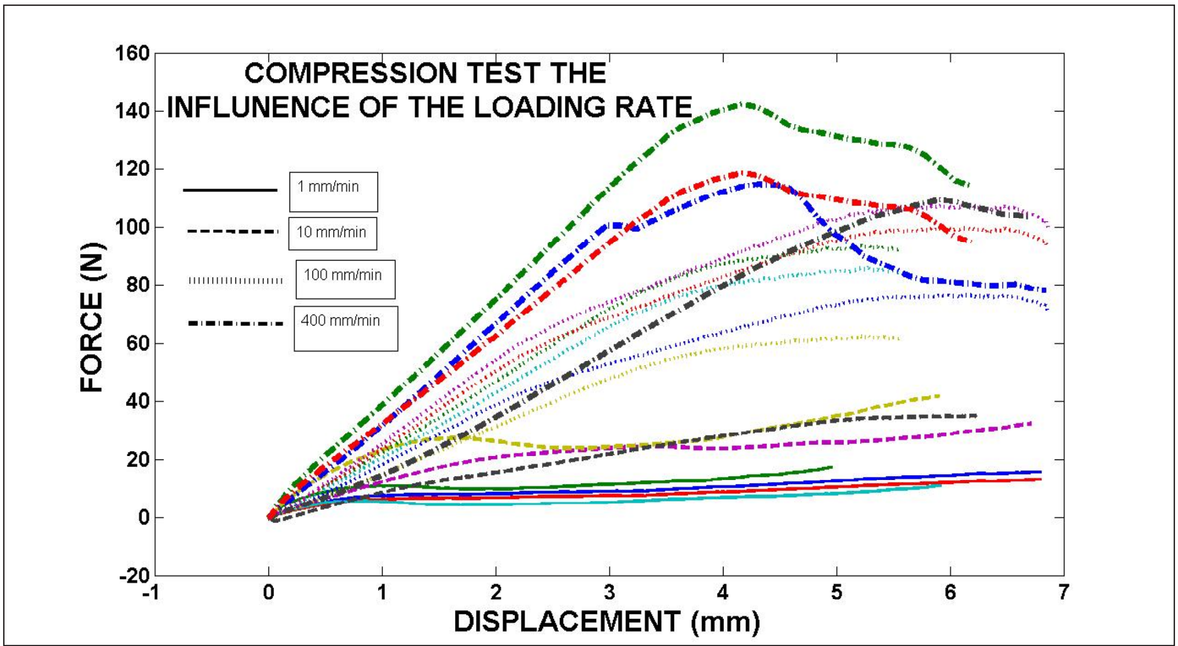
3: *Tension loading of the skin specimens*



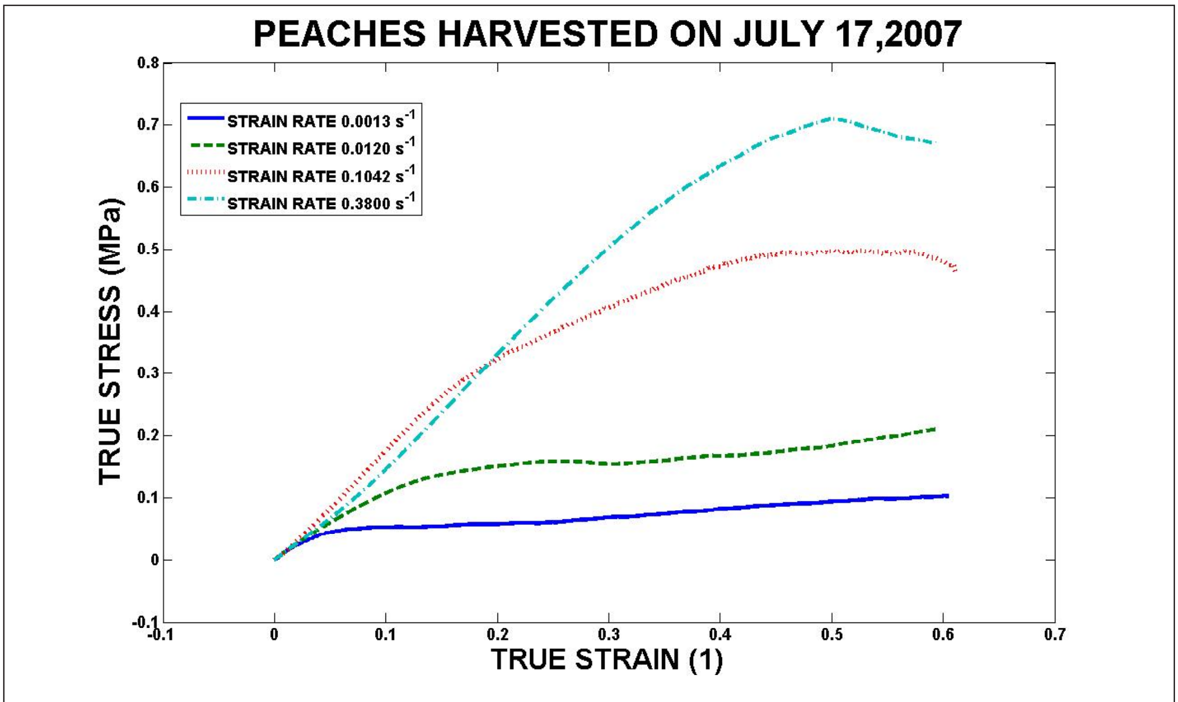
4: *The experimental records of the force vs. Displacement for single skin specimens*

Compression testing of the mesocarp

The specimens of the mesocarp have been tested at the different strain rates. Specimens of the cylindrical shape (20 mm in diameter and about 14 mm in thickness) have been used. At least five experiments have been performed at each strain rate. In order to achieve the different strain rates, two kinds of the experiments have been performed. First, the compression tests using the TIRA testing equipment have been performed. The different cross – head rates (from 1 mm/min up to 400 mm/min) have been used in order to achieve the different strain rates. Examples of the experimental records force – displacement are displayed in Fig. 5. These data have been converted into stress – strain dependences – see Fig. 6. The influence of the strain rate on the stress is shown in the Fig. 7. The material exhibits a typical viscoelastic behaviour. This type of deformation can be explained by Maxwell model, which consists of a dashpot and a spring in series. The spring represents the deformations that occur due to the bending and stretching of interatomic bonds. If a nonlinear spring is used, the deformations are similar to those occurring due to the uncoiling of portions of molecular chains. Extensions in the dashpot are not recoverable and they represent the result of intermolecular slippage. The observed behavior, when the mechanical model is subjected to a tensile stress, depends on the rate of loading. Other correlations can be made with the mechanical model, such as the effect of temperature on the mechanical behavior.



5: *The influence of the cross-head velocity on the force during the peach compression*

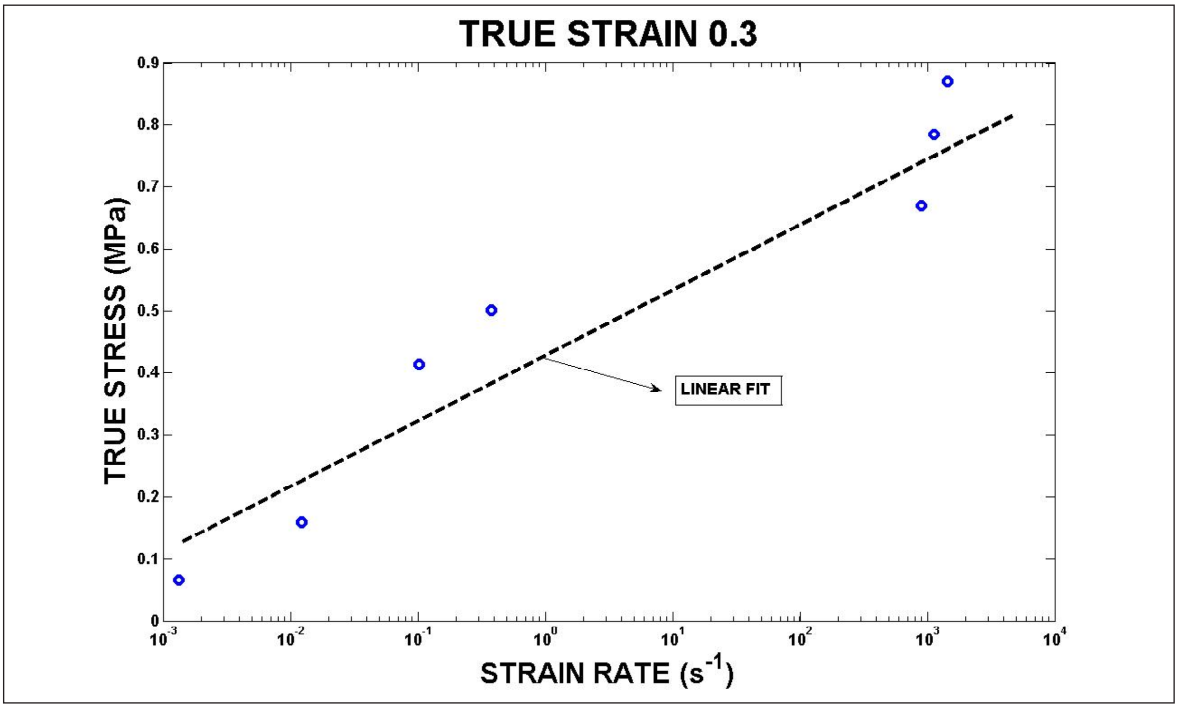


6: *Stress – strain curves at different strain rates*

At higher temperatures the viscosity in the dashpot decreases resulting in greater extensions, while at lower temperatures the dashpot becomes more viscous and failure occurs before appreciable extension (Sorvari, 2006). Maxwell model is a basic deformation model for polymers. Several other models such as Kelvin model and Standard Linear Solid model are modifications of this model developed for better description of deformation behavior. The shear relaxation is described for the Maxwell model by:

$$G(t) = G_\infty + (G_0 - G_\infty)e^{-\beta t}, \quad (1)$$

where G_0 is the instantaneous shear modulus, G_∞ is the long term shear modulus and β is the decay constant. For the evaluation of the strain, ε_{ij}, and stress, S_{ij}, deviators the Jaumann rate formulation is used:



7: *Example of the strain rate influence on the true stress*

$$S_{ij} = 2 \int_0 G(t - \tau)\, \varepsilon_{ij}(\tau) dt. \quad (2)$$

The equation for the Kelvin model is:

$$S_{ij} + 1/\tau\, S_{ij} = (1 + \delta_{ij})\, G_0 \varepsilon_{ij} + (1 + \delta_{ij})\, G_\infty /\tau\, \varepsilon_{ij}, \quad (3)$$

where δ_{ij} is the Kronecker delta and $\tau = 1/\beta$. The parameters for both models are given in the Tables I and II – see also Buchar et al. (2008).

I: *Maxwell model (ρ_0 – material density, K – modulus of the compressibility)*

Parameter	ρ_0 (kg/m³)	K (GPa)	G_0 (GPa)	G_∞ (GPa)	β (s^{-1})
Value	970	0.01333	0.00280	0.0014	0.00043

II: *Kelvin model (ρ_0 – material density, K – modulus of the compressibility)*

Parameter	ρ_0 (kg/m³)	K (GPa)	G_0 (GPa)	G_∞ (GPa)	β (s^{-1})
Value	970	0.01333	0.00280	0.0014	8000

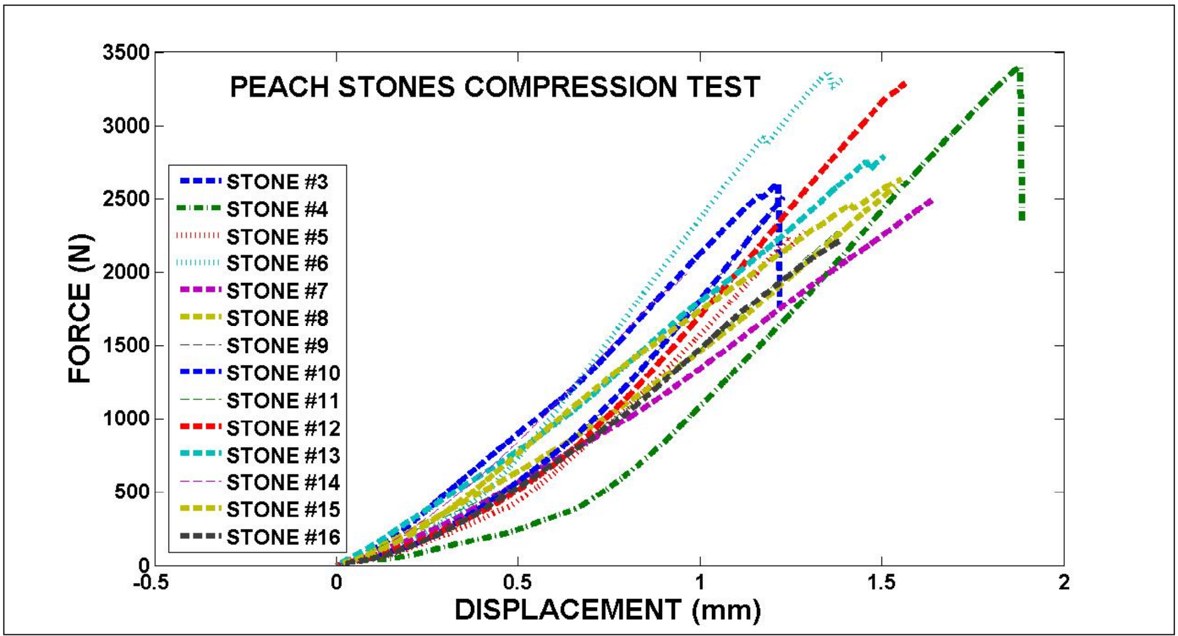
Compression testing of the peach stones

The stones have been compressed between two flat plates. The examples of the loading curves are shown in Fig. 8. The obtained data show that the stones behave as an elastic body. The apparent Young modulus *E* has been evaluated using the theory outlined e.g. in ASAE (2001). Its average value was about 20 MPa. The Poisson ratio was estimated to be about 0.3.

Explosive loading

Explosively loaded peaches have been much softer in comparison with equivalent static compression. In some cases the skin of the peach remained undamaged. By the explosive loading the juice is released in the whole volume. The description of this process must involve some other equations like Darcy-Brinkman. Used constitutive equation can only describe some initial stage of the peach behaviour.

The obtained data on the mechanical properties of the main parts of the peach have been used for the design of the peach numerical model.



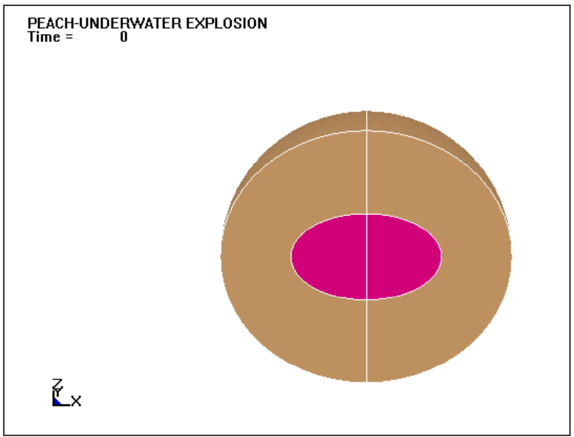
8: *Curves force–displacement at cross–head velocity 20 mm/min*

Numerical model

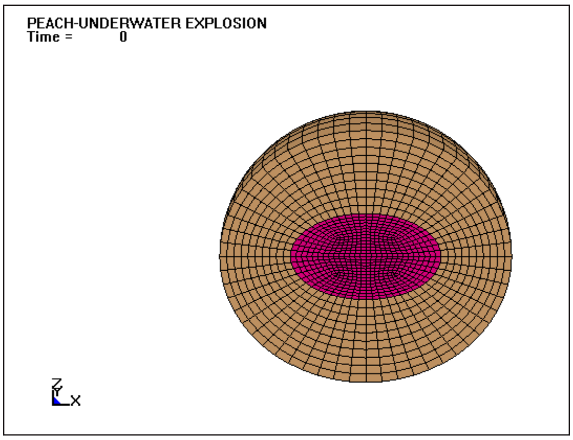
The real shape of the peach has been considered as a sphere. The stone is taken as an ellipsoid.

The numerical solution is based on the method of the finite elements. The mesocarp of the peach and the stone is divided into 132980 brick elements. The schematic of the peach model is shown in the Fig 9a. The skin is divided into 150 shell elements – see Fig. 9b.

The numerical simulations have been performed using LS DYNA 3D finite element code.



9: *a) Cross section of the computational model*



b) Finite element distribution in the peach

Numerical results

In Figs 10a and 10b, the examples of the pressure wave propagation in the water are displayed.

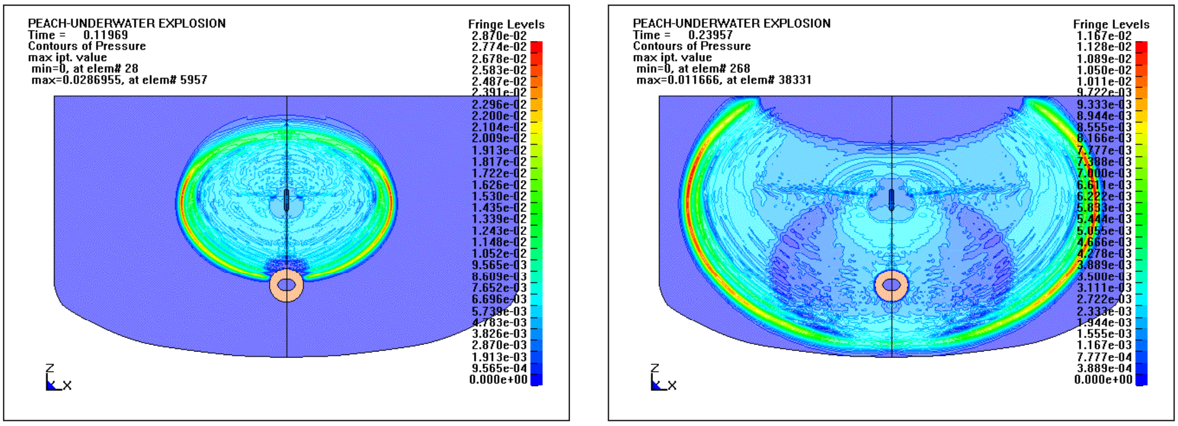
Following quantities have been evaluated from big amount of obtained data: pressure on the peach surface, displacement and surface velocity.

The computation was performed for two admissible models of the peach mesocarp. In Fig. 11 the pressure history on the peach surface is shown.

A comparison between two used models is displayed in Fig. 12.

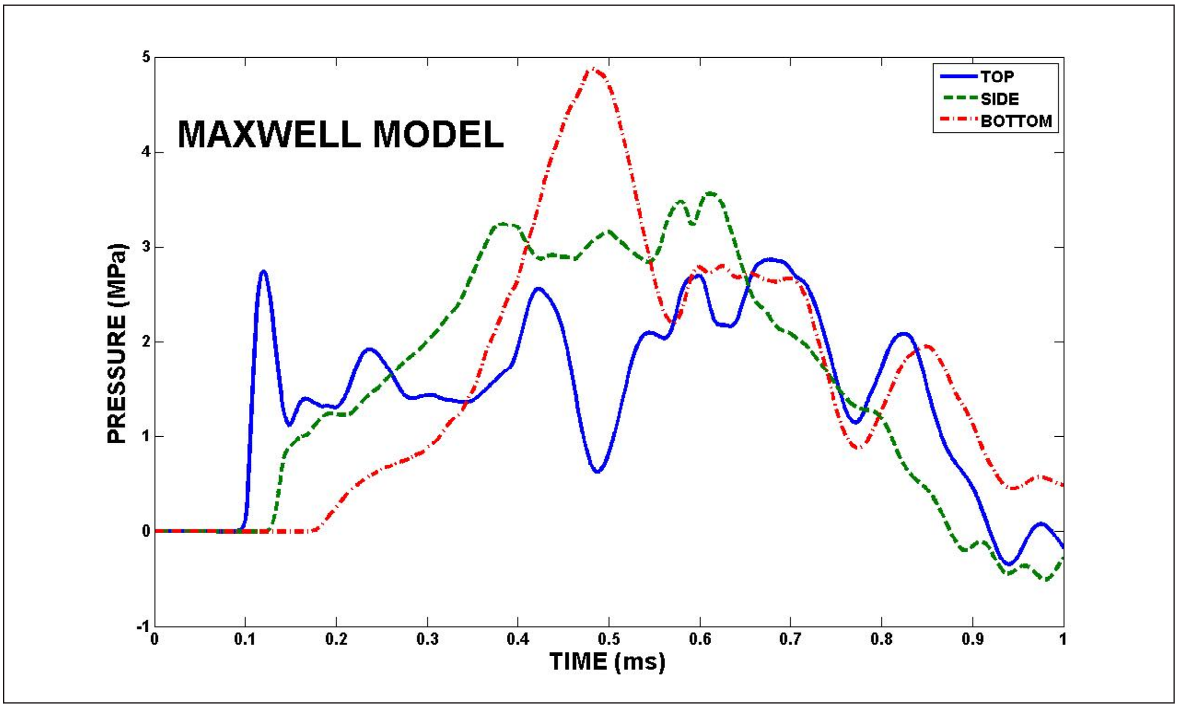
One can see that the differences are very small if not negligible. The same is valid for the displacements. The displacements at the different points on the peach surface are shown in the Fig. 13.

It is evident that the displacement is non homogeneous. The maximum of the displacement at the top of the peach is at least twice higher than that at the bottom of the peach. The time histories also differ qualitatively. The values of the displacement are lower than those observed at the tensile test – see Fig. 4. It is in agreement with results of the observation of explosively loaded peaches (no fracture).

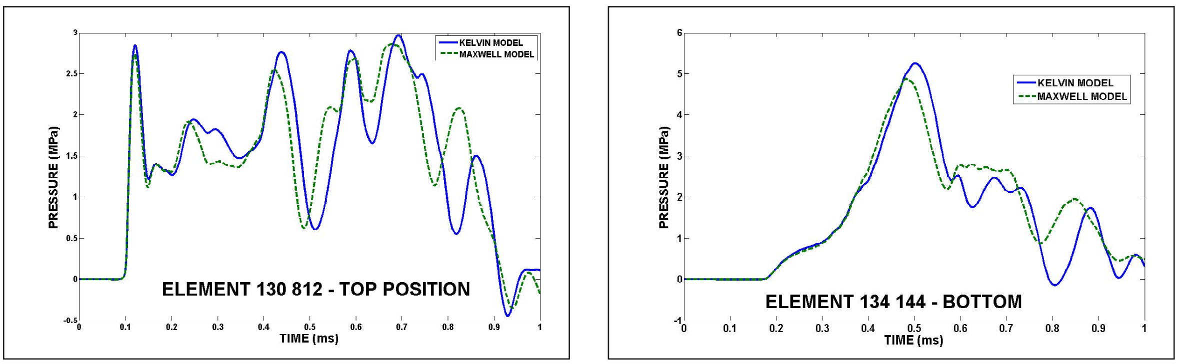


a) *b)*

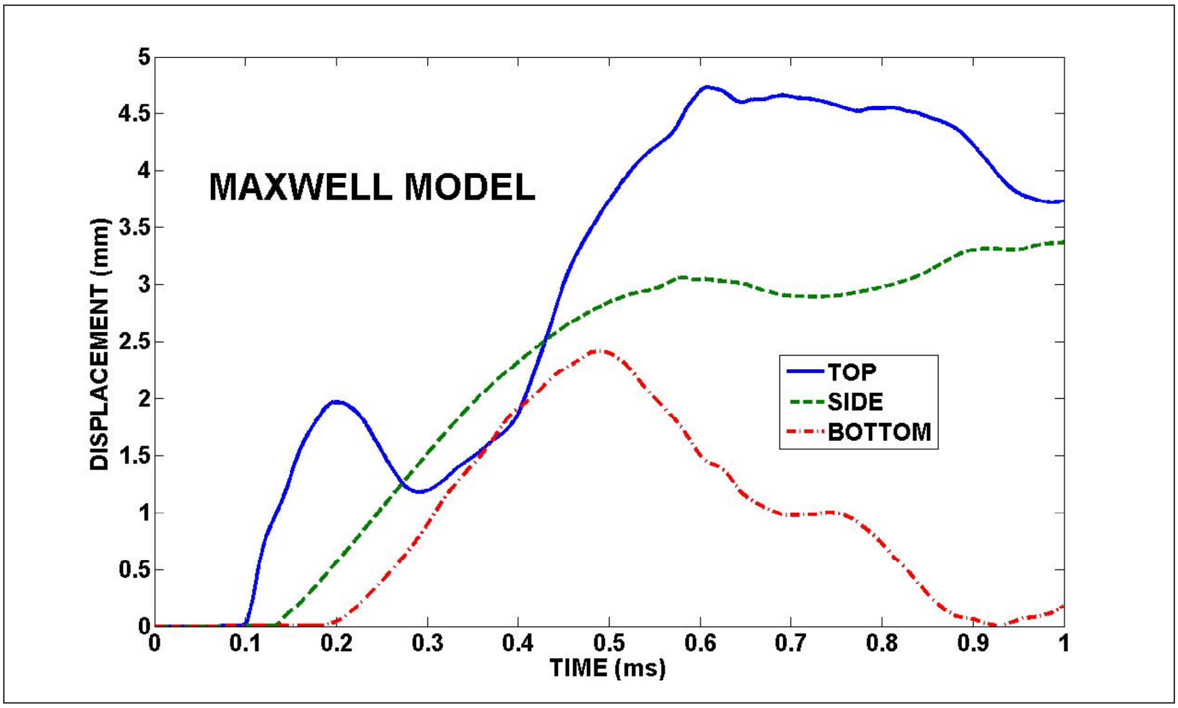
10: *Contours of the pressure*



11: *Pressure–time history on the peach surface*



12: *Comparison between Maxwell and Kelvin models*



13: *Distribution of the surface displacements*

SUMMARY

In the given paper the model of the peach has been developed. This model is based on many experiments, which were performed in order to obtain the constitutive equations of main part of the peach. It has been found that the behaviour of the peach skin as well as peach stone can be described in terms of elasticity. The corresponding elastic constants have been evaluated. The mechanical properties of the mesocarp exhibited significant strain rate dependence. This phenomenon has been described using the theory of viscoelasticity. Two different models, Maxwell and Kelvin, have been used. The obtained data have been used for the numerical simulation of the peach behaviour under underwater shock loading. The results of this simulation show the agreement with results of the observation (undamaged peach skin). The numerical simulation also gives some insight on the details of this loading, which is more and more tested as a tool of fruit treatment. It has been shown that using a pressure, it was possible to produce soft peaches, and get juice squeezing by hand. For the foods containing water like peaches, apples etc., it is possible to be softened by underwater shock wave treatment. In contrast, dried foods (containing little water) are not softened but they are grinded by the same treatment. In this case, the grinding preprocess must be considered. The food sample that needs to be softened is separated into two or more pieces. The study of this phenomenon will be subject of the forthcoming papers.

SOUHRN

Chování broskví při výbuchovém zatěžování pod vodou

Práce obsahuje úvodní informace o chování broskví, které byly umístěny ve vodní nádrži a zatěžována podvodním výbuchem nálože trhaviny. Jde o postup, který se stává středem pozornosti ve výzkumu potenciálních technologií zpracování ovoce a jiných zemědělských a potravinářských produktů. Výhodou daného postupu je možnost získat ovocné šťávy ve výrazně větším objemu než v případě použití stávajících postupů. Cílem práce byla zejména numerická simulace daných experimentů. K tomuto účelu byl navržen model broskve, a to na základě experimentálního výzkumu mechanického chování hlavních složek broskve (slupka, dužina a pecka). Ukazuje se, že zatímco slupka a pecka se chovají jako pružná tělesa, dužnina vykazuje poměrně výraznou závislost na rychlosti deformace. Tato závislost byla popsána pomocí Kelvinova a Maxwellova modelu viskoelastického chování. Numerická simulace byla provedena pomocí programu LS DYNA 3D, založeného na metodě konečných prvků. Výsledky umožnily získat představu o průběhu zatěžování, o časovém průběhu zatížení a posunutí na povrchu broskve. Ukazuje se, že některé výsledky numerické simulace souhlasí s výsledky experimentů (neporušená slupka). Výsledky celkově vytvořily podklad pro následné exaktní hodnocení daného postupu, jehož stále rostoucí používání je možné očekávat.

broskev, zatěžování rázovou vlnou, numerická simulace

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