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EVALUATION OF BRIE CHEESE MATURITY FROM INDENTATION TEST

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Abstract

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Rheological properties of Brie cheese with different time of ripening (1, 3, 4, 5, 6, 7 and 8 weeks) were evaluated. This evaluation has been performed using the indentation test at the constant speed of the indentor penetration (20 mm/min). Two types of the indentors (bar and ball) have been used. The hardness of the cheese increased during the first three weeks of the ripening and than it decreased. The properties evaluated from the indentation test approved the isotropic behaviour of the tested cheese. The viscoelastic properties of the tested cheese have been obtained. The se properties were achieved using a methodology enabling to convert the indentation force–displacement response into the stress–strain relations. The obtained viscoelastic properties are independent on the used type of the indentor.

Brie cheese, ripening, indentation, viscoelasticity, stress, strain modulus

The understanding and characterization of mechanical properties of food materials is very important for a number of reasons such as (1) quality control for finished food products; (2) optimisation of processing parameters; and (3) understanding interrelationships between food structure and functional properties.

There are many types of tests that have been used for measuring the constitutive properties of foods. These tests range from those where the strain distribution is uniform, such as the uniaxial compression and tension tests, to those where the strain distribution is nonuniform, such as the indentation test. The former tests are used as standards for conventional structural materials because the measured forces and displacements can be converted into the stress–strain properties using simple theories, but they can be tedious and difficult when applied to soft foods because of the need to prepare specimens of specific size and shape.

The indentation test has been used more than a century for measuring hardness of materials (Tabor, 1951). Various types of depth sensing indentation tests have also been developed for the determination of mechanical properties (hardness, elastic modulus) of materials such as polymers (Briscoe and Sebastian, 1996), ceramic pastes (Briscoe and Özkan, 1997), and biomaterials (Turner *et al.*, 1999). These techniques are preferred because they are relatively fast and easy to perform, they do not require samples with strict shape requirements, and they may be performed without the destruction of the samples. These techniques are also widely used to measure the mechanical properties of foods (Özkan *et al.*, 2002; Anand and Scanlon, 2002; Goh *et al.*, 2005).

The objective of this study was to apply a recently used method (Nedomova, 2010) to obtain the constitutive properties of viscoelastic materials from the indentation test. Brie cheese specimens were tested in indentation. The influence of the ripening time was investigated. Two types of the indentors have been applied. The bar indentor has been used in order to obtain data which will be compared with the results of the dynamic test (see e.g. Nedomova, 2009). Spherical indenter, who simulates the actions of a cheese grader when "thumbing" a cheese (Harper, 1952; Green *et al.*, 1985; Prentice *et al.*, 1993), was also investigated in this paper.

MATERIAL AND EXPERIMENTAL TECHNIQUE

The experiments were carried out on blocks of certified origin Brie cheese, manufactured by a company located in Czech Moravia highland. The cheese has form of a cylinder (diameter about 230 mm, height about 35 mm). Example of the Brie cheese block is shown in the Fig. 1.

1: *Photo of the Brie cheese block. L, T – direction of measuring*

The pieces were matured in chambers where relative humidity and temperature were maintained according to the company procedures. The blocks of cheese have been tested at one week (February 5, 2009), three weeks (February 19, 2009), four weeks (February 26, 2009), five weeks (March 5, 2009), six weeks (March 12, 2009), seven weeks (March 19, 2009), and eight weeks (March 26, 2009), after the production.

Experiments were performed at 23 °C using the TIRATEST testing machine (Germany). Axisymmetric indentation tests were performed at constant speed 20 mm/min using both spherical indenter 10 mm diameters, $D = 2R$, and bar indenter (6 mm in diameter), respectively. The measurement has been performed in two directions shown in the Fig. 1 (L and T).

EXPERIMENTAL RESULTS

In the Fig. 2 examples of the force – displacements (penetration) records are displayed.

The force increases up to maximum that it falls and remains nearly constant. The same qualitave features have been found during the ball indentation. The observed features of the force development during indenter penetration are consequence of the development of the cheese structure. In the Fig. 3 the cross section of the cheese is shown.

The structure is characterized by a crumb, which develops during the cheese ripening. It means the maximum of the force corresponds to the moment of the crumb breakage. The scatter in the experimental data can be connected with occurrence of many voids in the cheese. The more detail view on the cheese structure is shown in the Fig. 4.

The next parameters were evaluated:

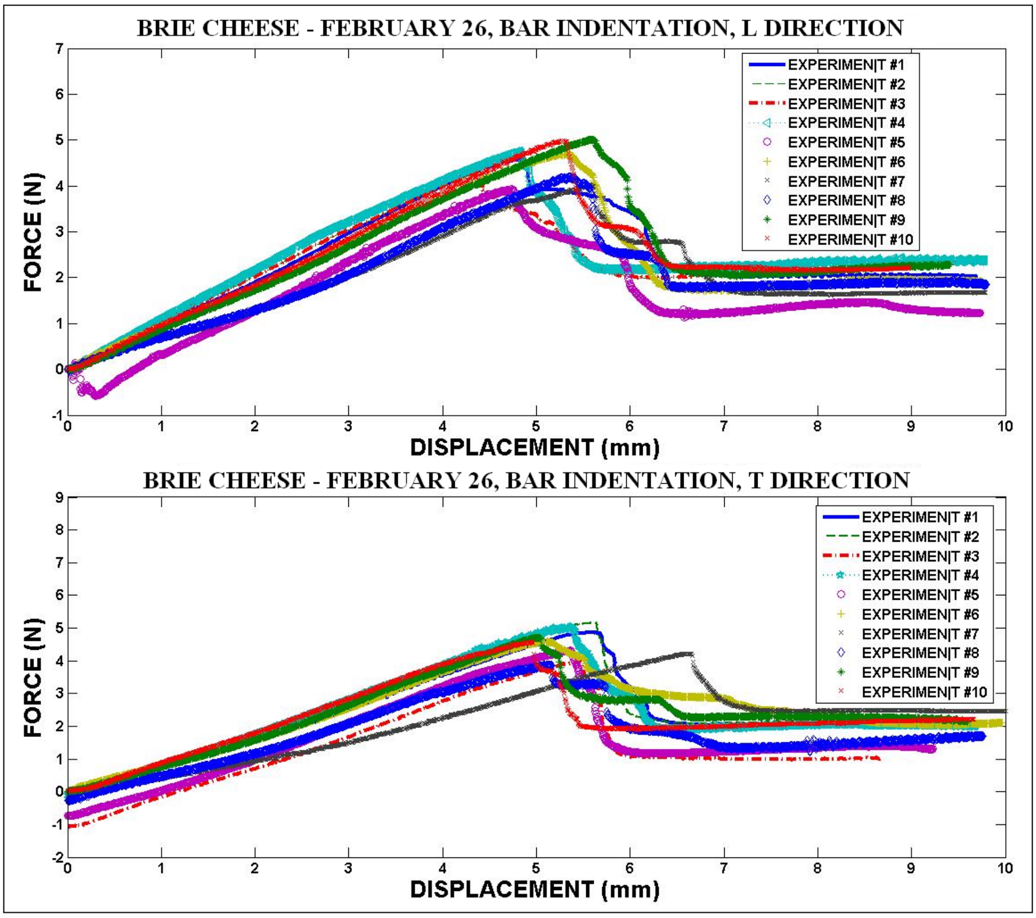
- Breaking force (N) corresponding to force at the major failure event. It was considered as empirical measure of the crumb strength.
- Displacement, x_{max}, at fracture.
- Work, W, (J) corresponding to the area under the force F – displacement x curve until the breaking event occurred. This parameter has been used as empirical index of toughness.

Its value is given by the relation:

$$W = \int_0^{x_{max}} F(x)dx.$$

Twenty experiments have been performed for every time of the cheese ripening (ten experiments in the L direction and ten experiments in the T direction).

In the Fig. 5 the influence of the ripening time on the breaking force (maximum of the force) at the bar penetration into the cheese is shown.



2: *Force – displacement records*

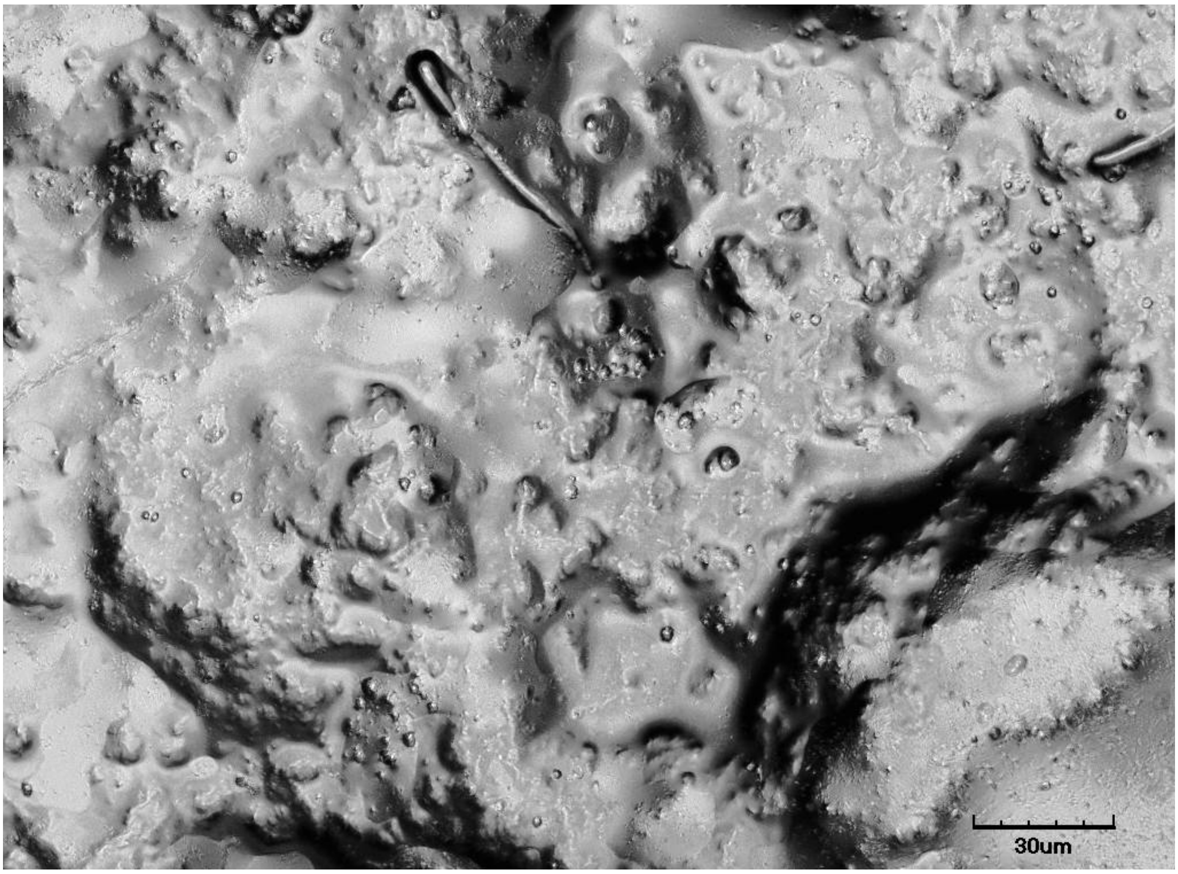
3: *Cross section of the Brie cheese. Three weeks of the ripening.*

It is obvious that the breaking force the cheese crumb increases up to some maximum and than decreases. There are no statistically signifiant differences between the forces measured in the L and T directions. The same conclusions are valid also for the forces found during the ball penetration – see Fig. 6.

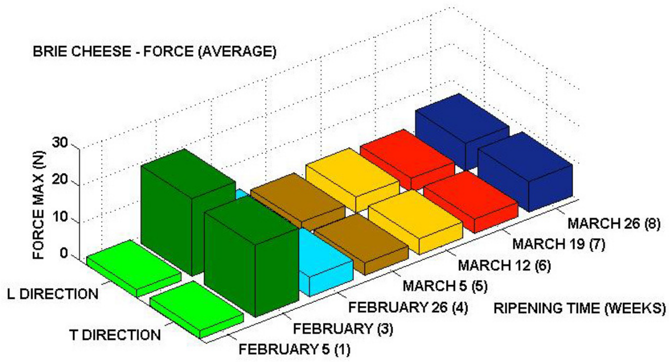
The values of the forces are higher for the ball penetration. In the Fig. 7 the displacement at the force maximum is displayed.

The difference between results from bar and ball indentation tests is illustrated in the Fig. 8.

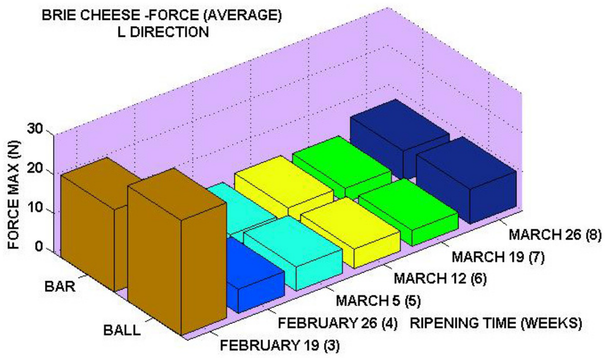
The displacement increases with the ripening time. The values of the work W correspond to the values of the breaking force. The value of this parameter is displayed in the Fig. 9 and 10.



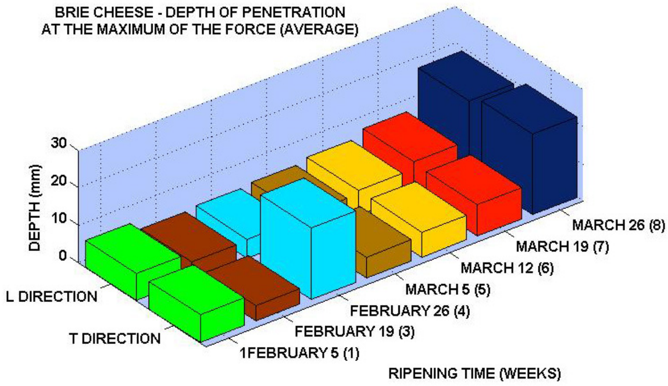
4: *Detail of the cheese structure – three weeks of the ripening*



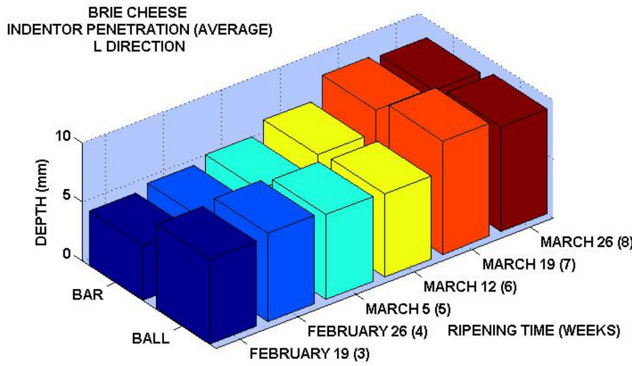
5: *Bar indentation – the influence of the ripening time on the maximum of the force*



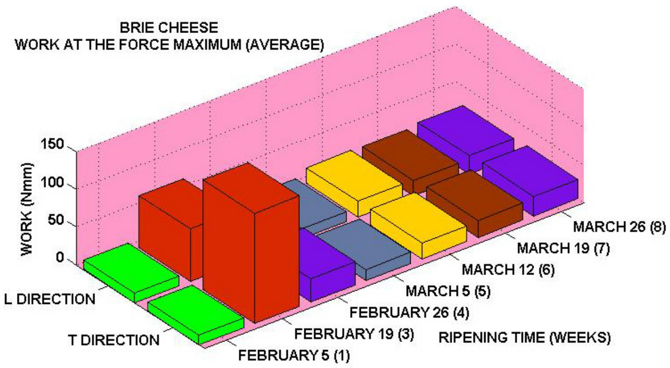
6: *Ball and bar indentation*



7: *Displacement of the bar indenter at the force maximum*



8: *Comparison between depths of the ball and bar indenters*



9: *The changes in the average values of the work, W, given by the Eq. (1)*

The obtained data enable to describe the development of the Brie cheese rheological properties during its ripening. The used parameters are semi empirical. The true description of these properties must be expressed in terms of constitutive model. It is well known that the cheese behaves as viscoelastic solids. The procedure how to obtain parameters of this model from the indentation test data has been described in the previous work (Nedomova, 2010). The viscoelastic modulus $E(t)$ is given (Sakai *et al.*, 2002) as:

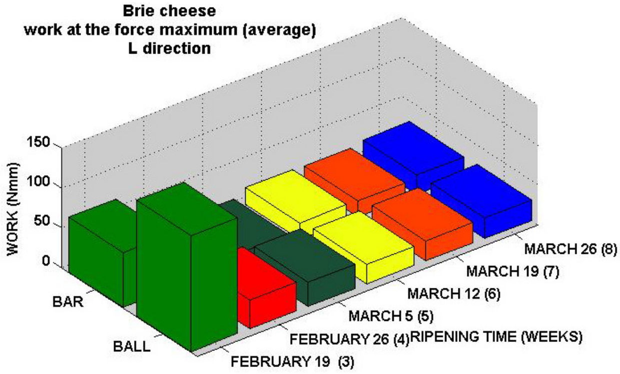
$$E(t) = \frac{4(1-\nu^2)}{\sqrt{R}k_s}\left(\frac{\gamma_s}{2\pi\nu_o}\right)^{\frac{3}{2}} L^{-1}\left[s^{\frac{3}{2}}P(s)\right],$$

where R is the ball radius, ν is the Poisson's ratio, $k_s = 4/\pi$, $\gamma_s = 2$,v_o is the indenter speed and $P(s)$ is the Laplace transform of indentation load $P(t)$ with the transform variable s.

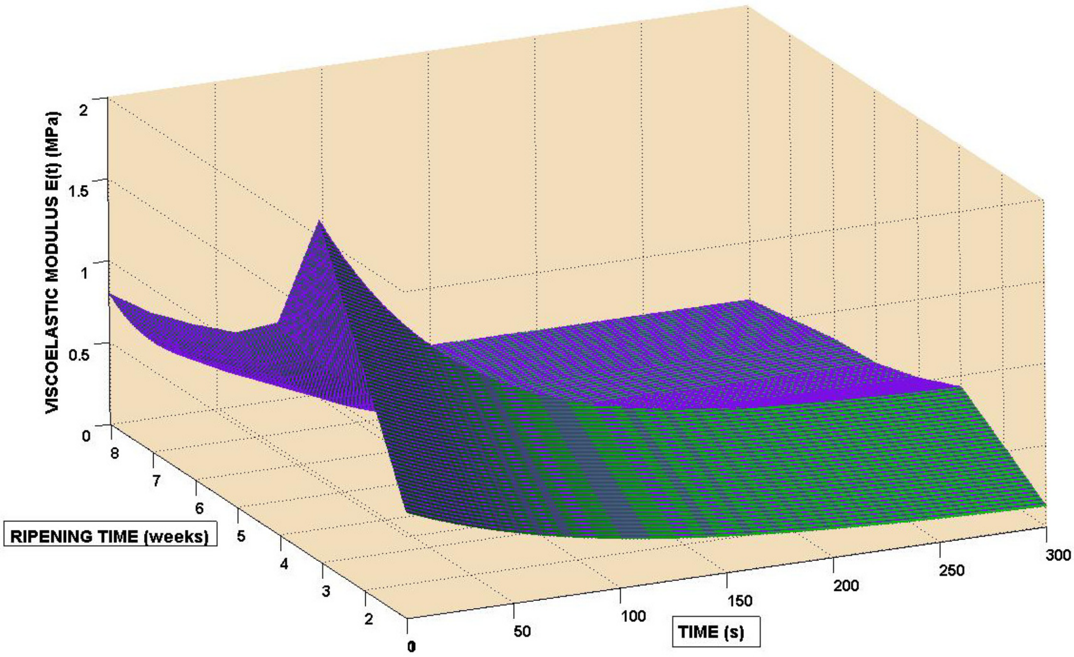
The analysis of the force F – depth of the penetration, h up to the depth at the force maximum x_{max} released that this dependence can be fitted by the polynom:

$$P(t) = ah^3 + bh^2 + ch + d,$$

where $h = v_o t$. The use of the MATLAB software enables to express the inverse Laplace transform as:



10: *Work done during the penetration of the bar and ball indenters*



11: *The influence of the time of the cheese ripening on its viscoelastic modulus*

$$L^{-1}\left[s^{\frac{3}{2}}P(s)\right] = 6av_o^{\,3}L^{-1}\left(s^{-\frac{5}{2}}\right)+2bv_o^{\,2}L^{-1}\left(s^{-\frac{3}{2}}\right)+\frac{cv_o}{\sqrt{\pi t}}+dL^{-1}\left(s^{\frac{1}{2}}\right).$$

The numerical procedure outlined e.g. in (Brančík, 1998) has been used. The results of the numerical computations are shown in the Fig. 11. The computation has been performed for $\nu = 0.45$. The results are not too sensitive to some changes in the value of this quantity.

The viscoelastic modulus decreases with the time. The velocity of this decrease increases with the time of the ripening. Instantaneous value of E follows the conclusions obtained from the results of the indentation tests. This value of the modulus describes the initial response of the cheese to the loading. For longer time this modulus decreases to some asymptotic value. It is obvious that this modulus, i.e. $E = E(t \rightarrow \infty)$ is affected by the time of the cheese ripening significantly less than the value $E\,(t = 0)$. It means the degree of the cheese maturity plays dominant role namely for he short time loading (impact etc.).

CONCLUSSIONS

Results obtained in the given paper give information on the mechanical response to the indentation by the two types of the indenters. It has been found that the qualitative features of this response are independent on the shape of the indentor (ball or bar). The indentation test reflects the observed development of the cheese structure. The mechanical response of the Brie cheese is significantly affected by the development of the cheese crumb.

This crumb is much more strength than the inner part of the cheese. The hardness of this surface layer is highest at the third week of the cheese ripening. In the following time this strength rapidly decreases. The higher resistance against indenter penetration has been observed for the ball indenter. The experimental results have been interpreted in terms of the theory of the viscoelasticity. The viscoelastic properties have been described by the viscoelastic (relaxation) modulus. This modulus decreases with the time. It has been shown that these moduli reflect the influence of the time of the ripening. The dependence of this modulus on the time suggest that the influence the time of the ripening on the rheological cheese behaviour is significant namely for the short time loading. For long – term loading process this influence is less expressive.

SUMMARY

Rheological properties of Brie cheese with different time of ripening (1, 3, 4, 5, 6, 7 and 8 weeks) were evaluated. This evaluation has been performed using the indentation test at the constant speed of the indentor penetration (20 mm/min). Two types of the indentors (bar and ball) have been used. The obtained experimental record force – indenter displacement (penetration depth) exhibited a maximum following by a nearly constant force. This behaviour corresponds to the cheese structure development. The maximum of the force corresponds to the fracture of the cheese crumb. The maximum of the hardness of the cheese increased during the first three weeks of the ripening and than it decreased. The values of this force as well as other parameters evaluated from the indentation tests are independent on the direction in the cheese. It means the Brie cheese behaves as the isotropic body during the whole time of its ripening. He qualitative features are also independent on the indenter geometry.

In the next step the viscoelastic properties of the tested cheese has been obtained. These properties were achieved using a methodology enabling to convert the indentation force–displacement response into the stress–strain relations. The obtained viscoelastic properties are independent on the used type of the indentor. It has been found that the degree of the cheese maturity plays dominant role namely for the short time loading (impact etc.).

SOUHRN

Hodnocení zrání sýru typu Brie pomocí penetračních testů

V rámci dané studie byly provedeny experimenty, kdy vzorky sýru Brie byly zatěžovány penetrací tyče a koule. Rychlost penetrace byla konstantní a rovna 20 mm/min. Byly provedeny experimenty na sýrech po 1, 3, 4, 5, 6, 7 a 8 týdnech zrání. Veškerá měření byla provedena ve dvou vzájemně kolmých směrech. Cílem těchto měření bylo zjistit, zda reologické vlastnosti sýru závisí na orientaci. Výsledky ukázaly, že sýr Brie se chová jako izotropní těleso. Závislost síla – hloubka penetrace vykazuje nárůst síly a po náhlém poklesu následuje oblast, kde síla je téměř konstantní. Tento charakter průběhu síly odpovídá vývoji struktury sýru, kdy se vytváří povrchová vrstva (kůra) s výrazně odlišnými vlastnostmi ve srovnání s vnitřkem sýru. Maximum síly tak odpovídá okamžiku, kdy dochází k průrazu dané povrchové vrstvy. Velikost tohoto maxima nejprve roste s dobou zrání a dosahuje největší hodnoty ve třetím týdnu od výroby sýru. Pak následuje pokles. Tomu odpovídají i další veličiny, jako např. velikosti posunutí penetrátoru při lomu vrchní vrstvy sýru a práce vykonaná během této periody. Veličiny stanovené přímo z penetračních testů pak byly dále zpracovány v rámci teorie viskoelasticity. Byl použit přístup vyvinutý v předcházející práci (Nedomová, 2010) a byly stanoveny tzv. relaxační (viskoelastické moduly) E(t), což je v podstatě ekvivalent Youngova modulu pro elastická tělesa. Tato veličina závisí na čase. Její hodnota pro $t = 0$ udává okamžitou reakci tělesa na zatížení. Jde o tzv. okamžitý modul. V dalším průběhu modul klesá až k jisté hodnotě dosažené pro nekonečně velký čas. Tato veličina se nazývá rovnovážný modul. Ukazuje se, že okamžitý modul závisí na době zrání stejně výrazně jak síla potřebná k proražení povrchové vrstvy. Rovnovážný modul vykazuje sice kvalitativně shodnou závislost, ale méně výraznou. Je tedy zřejmé, že vliv zrání sýru na jeho deformační chování je nejvýraznější pro krátkodobá zatížení, např. v případě rázu jiného tělesa ap.

Brie sýr, zrání, penetrační testy, napětí, deformace, viskoelasticita, deformační modul

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