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CHANGES IN THE FORCE RELAXATION OF EDAM CHEESE DURING RIPENING

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Abstract

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The present study was performed to determine the influence of fat content and ripening time on changes in the viscoelastic properties and, separately, in the viscous and elastic properties of Edam cheese, based namely on the results of a stress–relaxation test. In order to obtain some more detail inside on the cheese rheological behaviour a limited number of the mechanical tests under compression has been performed. The significant effect of the loading rate has been demonstrated. The main aim was to describe the experimental results in terms of the semi-empirical Maxwell model, which describe the rheological properties of cheese during ripening. Results suggest that the tested cheeses behave like linear viscoelastic body. The fat content has no influence on the elasticity as well the viscosity of the cheese during its ripening.

stress relaxation, compression, elastic modulus, viscosity, Maxwell model, cheese ripening

The main quality characteristics of cheese are its rheological properties commonly referred to as body and texture or consistency (Messens *et al.*, 2000). Texture, besides appearance, flavour and nutritional value, is the main quality factor of food products (Rosenberg *et al.*, 1995). Cheese, as solid food, has viscoelastic nature, i.e. it exhibits both solid (elastic) and fluid (viscous) behaviour (Konstance and Holsinger, 1992). A popular mechanical test to characterize the viscoelastic properties of soft solid foods and other biological materials is stress relaxation. Del Nobile *et al.* (2007) used this test to characterize a variety of products. In stress relaxation tests, a constant strain is applied and the stress required to maintain the deformation is measured as a function of time. When a stress relaxation test is performed, different behaviours can be observed: ideal elastic materials do not relax whereas ideal viscous materials instantaneously show a relaxation. Viscoelastic solids gradually relax and reach an equilibrium stress greater than 0, whereas for viscoelastic fluids, instead, the residual stress vanishes to zero (Steffe, 1996). This method has been widely used for the study of the cheese viscoelastic properties (Sadowska *et al.*, 2009).

Rheological properties of cheese depend mainly on its composition (water, protein, fat, and salt content), pH value, protein degradation, and temperature (Luyten and van Vliet, 1996). Fat indirectly affects the water to protein ratio and regulates firmness and elasticity of cheese by increasing the moisture retaining property of curd (de Jong, 1987). Texture development in cheese occurs due to the breakdown of α_{s1}-casein during ripening (Lawrence *et al.*, 1987). Furthermore, milk fat normally provides a typical smoothness to a full fat cheese by being evenly distributed within the casein matrix of cheese.

In the given paper the influence of fat content and ripening time on changes in the viscoelastic properties of Edam cheese was studied using of a stress–relaxation test.

MATERIAL AND EXPERIMENTAL TECHNIQUE

The experiments were carried out on blocks of Certified Origin EDAM cheese (Eidamsky blok or Eidamska cihla in the Czech notation), manufactured by a company located in South Moravia. Semihard cheese called either Eidamský blok or Eidamská cihla are made in the Czech Republic since the 1920's. Their technological scheme is similar to the production of Gouda cheese (Kněz, 1960).

Cheeses with the fat content 30 and 45% have been tested. The pieces were matured in chambers where relative humidity and temperature were maintained according to the company procedures. Edam Cheese ripens under a ripening foil. The blocks of cheese have been tested at 16th (February 12, 2008), 39th (March 6, 2008), 60th (March 27, 2008), 79th (April 15, 2008), and 107th (May 13, 2008) day after the production.

Cylindrical samples, 20.0 mm in diameter, were cut from cheese blocks using a cork-borer, and next they were cut into cylinders, 12.6 mm in height. Two basic experiments have been performed. The basic rheological properties are given by the uniaxial compression. Specimen of the cheeses has been compressed to about 70% deformation at different crosshead speeds (1 mm/min, 10 mm/min, 100 mm/min). The next rheological properties were determined with a relaxation test run also on TIRATEST testing machine. Each sample was compressed to different heights at the crosshead speed 10 mm/min. To each height corresponds some level of the loading force. The compression anvil was then held in position for 300 seconds to maintain a constant strain. Time-dependent changes in stresses were recorded twice a second, using a computer program. The relaxation test data represent the average from five measurements. All experiments have been carried at the room temperature.

RESULTS AND DISCUSSION

In the Fig. 1 examples of the experimental records true stress – true strains are displayed.

One can see that there is a scatter of data. Average curves can be fitted by the function:

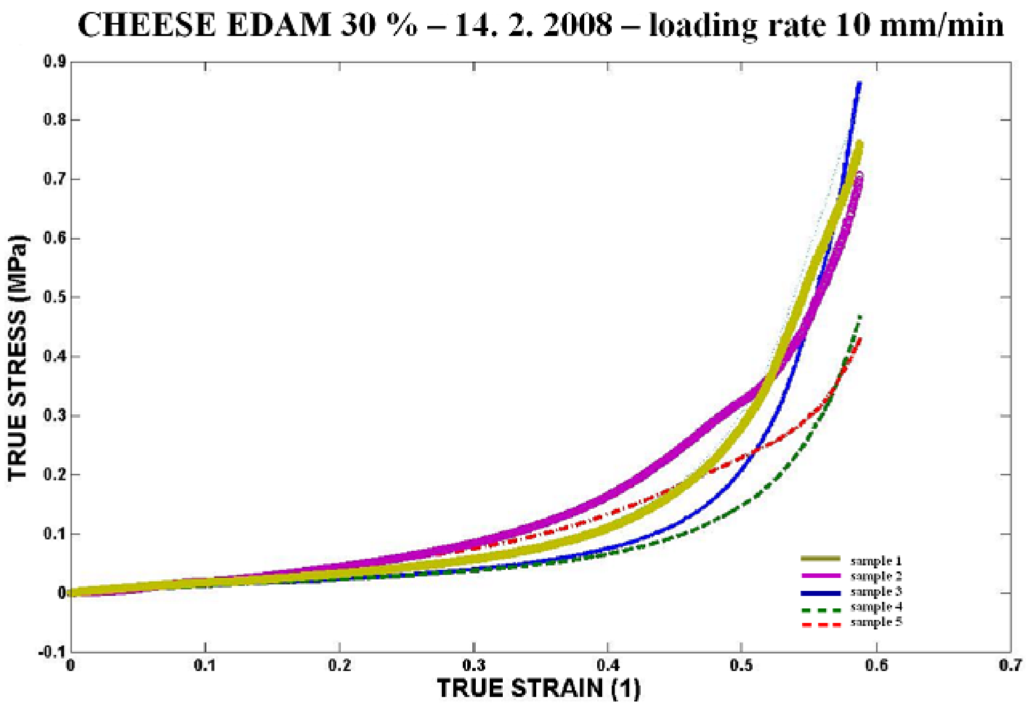
$$\sigma = Ae^{B\varepsilon}, \tag{1}$$

where σ and ε are the true strain and the true stress, respectively (Mancini *et al.*, 1999). *A* and *B* are constants and have to be regarded as fitting parameters. This function describes the stress strain curves obtained for Edam cheese of all stages of maturity. The values of the parameters *A* and *B* are given in the Tab. I.

The data enable to obtain the elastic modulus *E* as the tangent to the stress strain curve at the origin:

$$E = \frac{\partial\sigma}{\partial\varepsilon}\varepsilon = 0 \qquad E = AB. \tag{2}$$

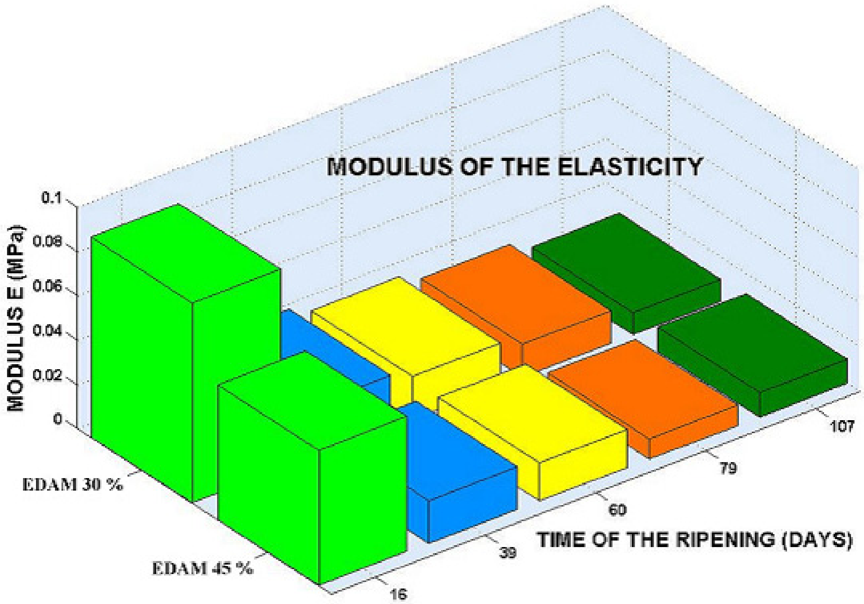
The values of the elastic moduli are shown in the Fig. 2. One can see that the elastic modulus decreases with the time of the cheese ripening as expected. The main changes occur at the beginning of the ripening. Elastic modulus also depends on the fat content. The increase of the fat content leads to decrease of the elastic modulus. The compression deformation properties described by the stress – strain curves are also dependent on the loading rate. The increase in the loading rate leads to the increase in the stress level at each value of the strain. This phenomenon is shown in the Fig. 3. Similar results have been achieved for all tested specimens of the Edam cheese. The investigation of this effect



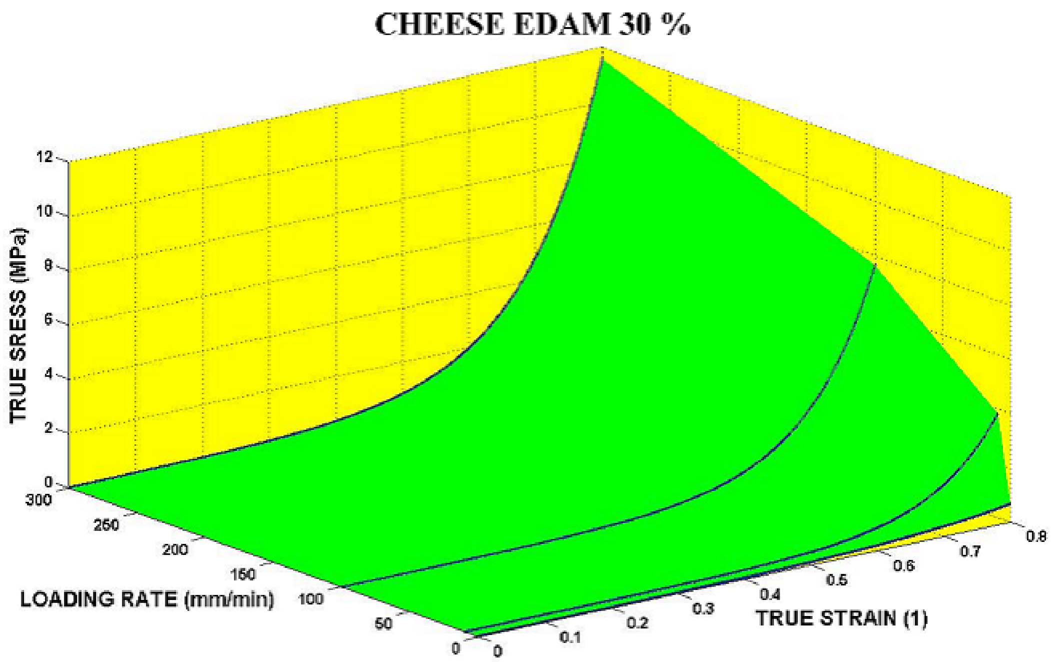
1: *Experimental records of the stress – strain curves*

I: *Parameters of Eq.(1). Loading rate 10mm/min*

DATE	EDAM 30%			EDAM 45%		
	A (MPa)	B (1)	R^2	A (MPa)	B (1)	R^2
14. 2. 2008	0.008595	10.500	0.9798	0.006101	9.950	0.9884
10. 3. 2008	0.003582	6.573	0.9660	0.003475	5.542	0.9666
28. 3. 2008	0.003119	6.152	0.9948	0.003005	5.700	0.9962
16. 4. 2008	0.001923	7.676	0.9972	0.001504	6.120	0.9892
14. 5. 2008	0.001439	6.901	0.9956	0.001101	9.950	0.9884



2: *Elastic moduli of the tested cheeses*



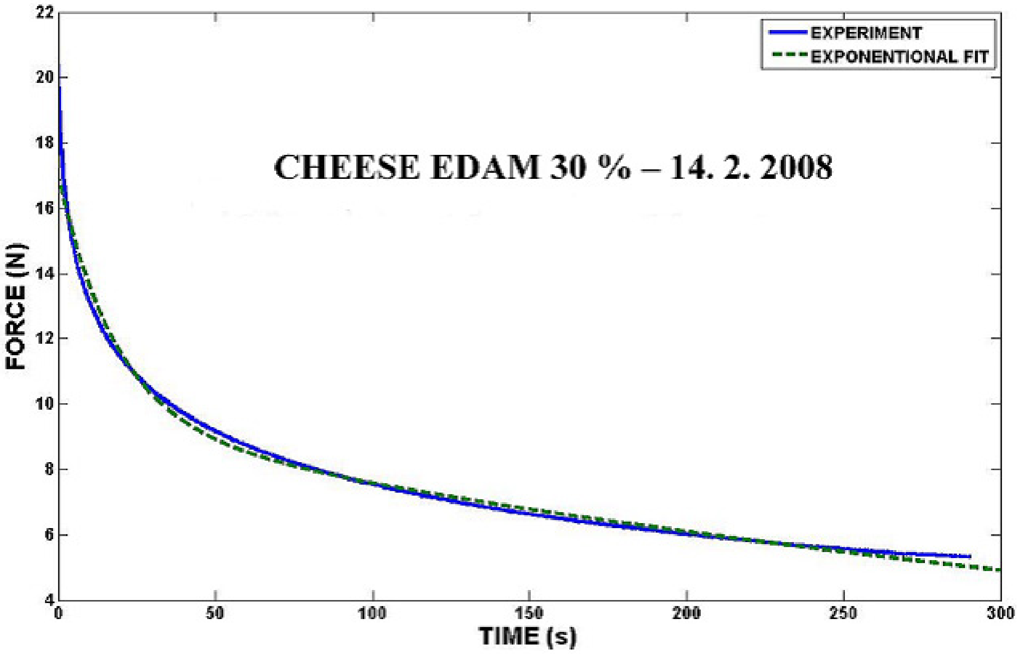
3: *The influence of the loading rate on the stress strain dependence* is not subject of this paper and it will be studied in some forthcoming papers. The aim of this preliminary presentation is to illustrate that the results discussed in the next sections have some limited validity.

The main attention has been focused on the stress relaxation curves. The specimens have been loaded to the different value of the force F_o. To this force corresponds to some level of the stress and the strain. Example of the experimental record of the relaxation curve is shown in the Fig. 4.

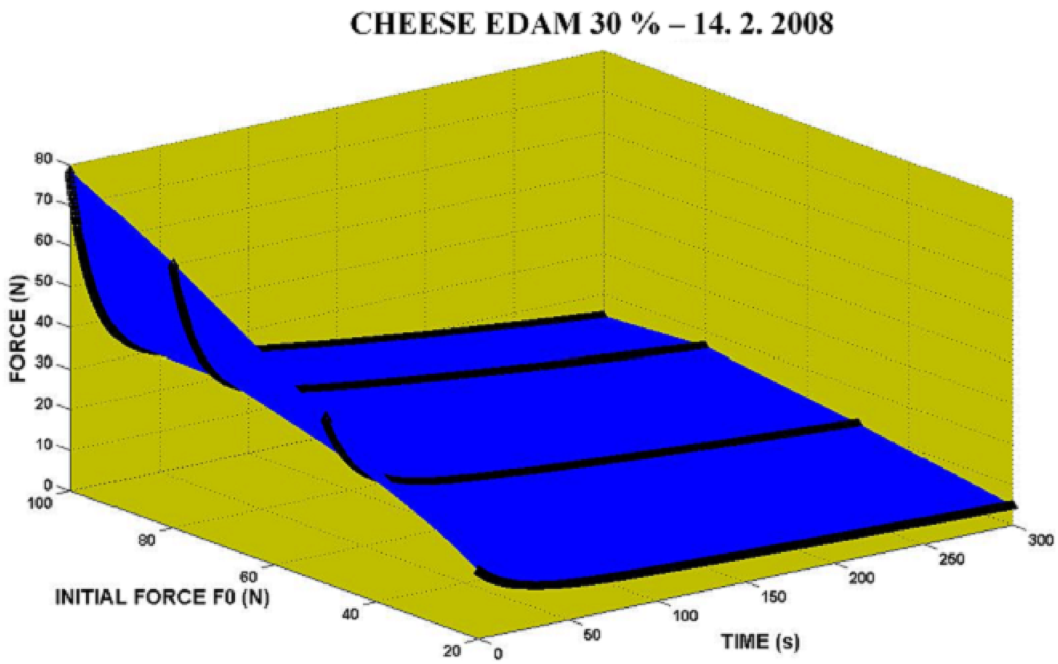
The same features exhibited stress relaxation curves obtained for all specimens tested at the different stages of their maturity and for all values of the preloading force F_o – see example in the Fig. 5.

The analysis of the data received that these data could be fitted by the function:

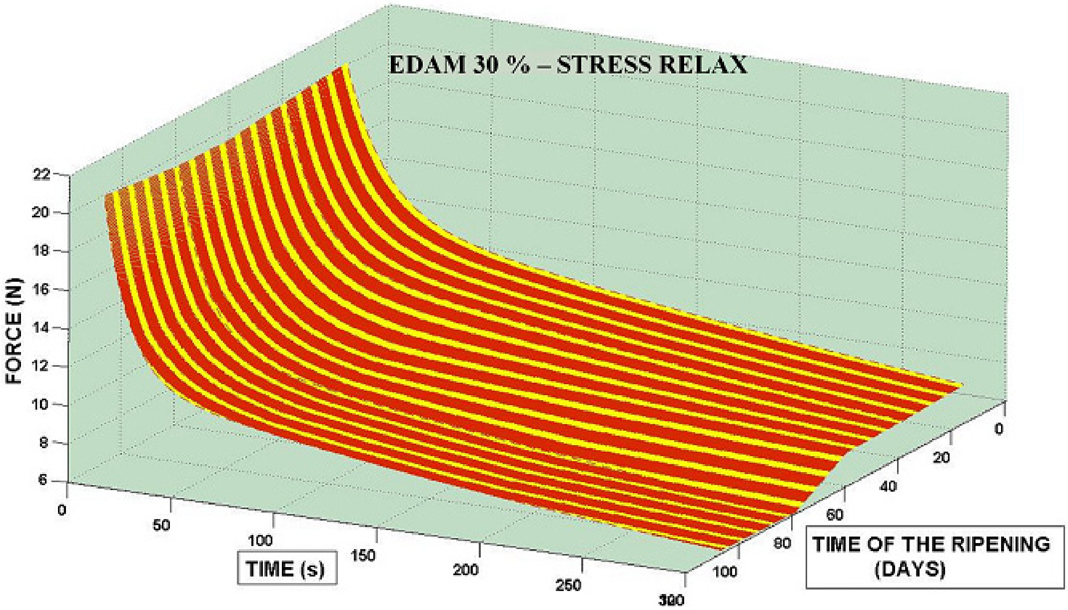
$$F = ae^{-bt} + ce^{-dt} + F_1.$$



4: *Relaxation curve of the cheese specimen. Loading rate 10 mm/min*



5: *Stress relaxation curves obtained for the different values of the preloading force F_o*



6: *Stress relaxation in the Edam cheese.* $F_o = 20$ N

The coefficient of Pearson's linear correlation between model and experimental points was higher than 0.997. Example of the influence of the time of the cheese ripening is shown in the Fig. 6.

In order to interpret the experimental data a generalized Maxwell model can be used. The model contains n Maxwell elements and a spring in parallel; each element consisting of dashpot in series (Bock *et al.*, 1989; Waananen and Okos, 1992; Watts and Bilanski, 1991). The generalized Maxwell model can be written as follows:

$$\sigma(t) = \sum_{i=1}^{i=n} C_i e^{-\frac{t}{\tau_i}} + \sigma_o,$$

where σ is the stress which is given by

$$\sigma(t) = \frac{F(t)}{S},$$

S is the cross section of the specimen. Owing to the Eq. (2) our model involves a parallel coupling of a Hooke's body and two Maxwell's bodies. The stress–relaxation behaviour of cheese can be than described as

$$E(t) = \frac{\sigma(t)}{\varepsilon_o} = E_1 e^{-\frac{t}{\tau_1}} + E_2 e^{-\frac{t}{\tau_2}} + E_o, \quad (3)$$

where ε_o is the strain corresponding to the force F_o. The parameter τ is usually expressed as:

$$\tau = \frac{\eta}{E},$$

where η is the viscosity. The Eq. (3) can be written as

$$E(t) = E_1 e^{-\frac{E_1}{\eta_1}t} + E_2 e^{-\frac{E_2}{\eta_2}t} + E_o, \quad (4)$$

The sum of the values of three elastic moduli (E_o+E_1+E_2) in the model can be used as an indicator of elasticity, while the sum of the values of two viscous (η_1+η_2) moduli – as an indicator of viscosity.

Parameters of the Eq.(4) are given in the Tables II–VI.

IIa: *EDAM cheese 30%. February 14, 2008.*

Strain	E_1 (MPa)	η_1 (MPas)	E_2 (MPa)	η_2 (MPas)	E_o (MPa)	$E_o+E_1+E_2$ (MPa)	$\eta_1+\eta_2$ (MPas)
0.2269	0.1071	1.9764	0.1352	62.9217	0.0438	0.2860	64.8981
0.2649	0.2363	3.8181	0.2578	121.1701	0.0853	0.5795	124.9882
0.2649	0.3861	5.3676	0.3667	166.7669	0.1434	0.8962	172.1345
0.2649	0.4255	5.5953	0.2941	111.9624	0.1709	0.8905	117.5577

IIb: *EDAM cheese 45%. February 14, 2008.*

Strain	E_1 (MPa)	η_1 (MPas)	E_2 (MPa)	η_2 (MPas)	E_o (MPa)	$E_o+E_1+E_2$ (MPa)	$\eta_1+\eta_2$ (MPas)
0.2746	0.0730	0.5259	0.0689	6.3723	0.0682	0.2101	6.8982
0.2925	0.2390	3.3626	0.2022	78.6249	0.0688	0.5100	81.9875
0.3855	0.3111	3.5038	0.2028	72.4810	0.0671	0.5810	75.9848
0.2684	0.5350	6.2065	0.4405	156.7059	0.1992	1.1747	162.9124

IIIa: *EDAM cheese 30%. March 10, 2008.*

Strain	E_1 (MPa)	η_1 (MPas)	E_2 (MPa)	η_2 (MPas)	E_o (MPa)	$E_o+E_1+E_2$ (MPa)	$\eta_1+\eta_2$ (MPas)
0.4378	0.0499	0.3369	0.0462	4.3155	0.0365	0.1326	4.6524
0.4378	0.1262	0.7032	0.0965	7.7996	0.0736	0.2962	8.5028
0.4559	0.2387	1.3058	0.1657	12.4432	0.1035	0.5079	13.7490
0.5491	0.2112	0.8835	0.1264	7.8767	0.0725	0.4100	8.7603

IIIb: *EDAM cheese 45%. March 10, 2008.*

Strain	E_1 (MPa)	η_1 (MPas)	E_2 (MPa)	η_2 (MPas)	E_o (MPa)	$E_o+E_1+E_2$ (MPa)	$\eta_1+\eta_2$ (MPas)
0.5247	0.0395	3.2795	0.0466	0.3043	0.0255	0.1116	3.5838
0.5357	0.1228	0.6752	0.0885	6.7082	0.0539	0.2652	7.3834
0.6120	0.2243	0.5821	0.0884	0.1427	0.0427	0.3554	0.7248
0.4078	0.4363	1.1923	0.1655	8.6191	0.0782	0.6800	9.8115

IVa: *EDAM cheese 30%. March 28, 2008.*

Strain	E_1 (MPa)	η_1 (MPas)	E_2 (MPa)	η_2 (MPas)	E_o (MPa)	$E_o+E_1+E_2$ (MPa)	$\eta_1+\eta_2$ (MPas)
0.5772	0.0523	0.8201	0.0377	31.1998	0.0215	0.1115	32.0198
0.6392	0.1242	1.6239	0.0694	18.7973	0.0454	0.2390	20.4212
0.5753	0.2384	1.8699	0.1103	30.0210	0.0545	0.4032	31.8909
0.6819	0.2664	1.6333	0.0970	22.6843	0.0480	0.4114	24.3176

IVb: *EDAM cheese 45%. March 28, 2008.*

Strain	E_1 (MPa)	η_1 (MPas)	E_2 (MPa)	η_2 (MPas)	E_o (MPa)	$E_o+E_1+E_2$ (MPa)	$\eta_1+\eta_2$ (MPas)
0.6901	0.0260	0.2289	0.0588	48.4460	0.0194	0.1042	48.6749
0.6964	0.1284	1.2983	0.0441	18.2580	0.0415	0.2139	19.5563
0.7617	0.1748	1.6487	0.0712	17.1748	0.0343	0.2802	18.8235
0.4999	0.3490	2.0735	0.1268	27.2071	0.0638	0.5396	29.2806

Va: *EDAM cheese 30%. April 16, 2008.*

Strain	E_1 (MPa)	η_1 (MPas)	E_2 (MPa)	η_2 (MPas)	E_o (MPa)	$E_o+E_1+E_2$ (MPa)	$\eta_1+\eta_2$ (MPas)
0.6487	0.0450	0.6346	0.0345	11.5881	0.0182	0.0977	12.2227
0.7156	0.1895	1.5472	0.0337	9.1226	0.0049	0.2282	10.6698
0.6365	0.2080	1.7903	0.0930	0.2506	0.0493	0.3503	2.0408
0.7500	0.1884	1.3547	0.0796	20.5623	0.0691	0.3371	21.9169

Vb: *EDAM cheese 45%. April 16, 2008.*

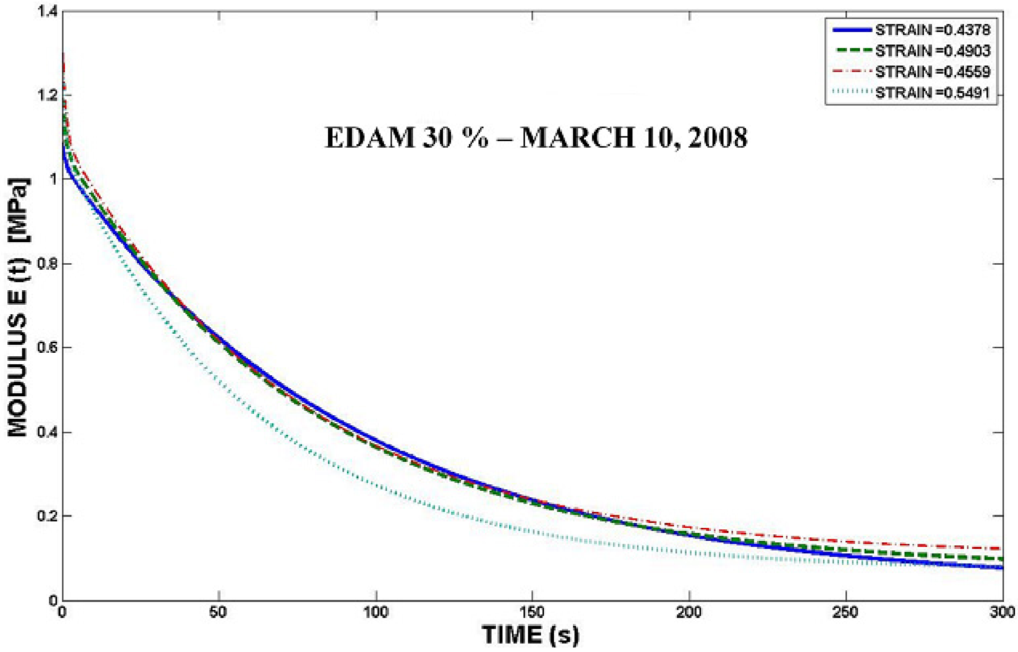
Strain	E_1 (MPa)	η_1 (MPas)	E_2 (MPa)	η_2 (MPas)	E_o (MPa)	$E_o+E_1+E_2$ (MPa)	$\eta_1+\eta_2$ (MPas)
0.7749	0.0421	0.4514	0.0236	6.0197	0.0159	0.0816	6.4711
0.7789	0.1063	0.7819	0.0406	9.1581	0.0250	0.1719	9.9400
0.8385	0.1819	0.9546	0.0538	12.4516	0.0351	0.2709	13.4062
0.5471	0.3016	1.6442	0.1150	1.7934	0.0844	0.5009	3.4376

VIa: *EDAM cheese 30%. May 13, 2008.*

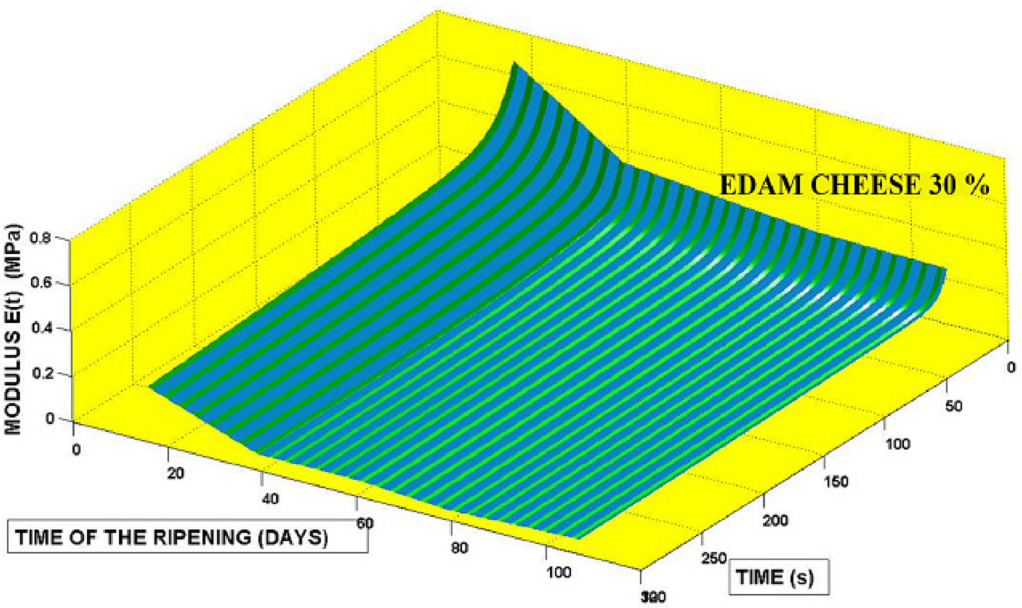
Strain	E_1 (MPa)	η_1 (MPas)	E_2 (MPa)	η_2 (MPas)	E_o (MPa)	$E_o+E_1+E_2$ (MPa)	$\eta_1+\eta_2$ (MPas)
0.6827	0.0441	0.5453	0.0326	10.5788	0.0266	0.1032	11.1241
0.7519	0.1141	0.8423	0.0500	13.1306	0.0066	0.1707	13.9730
0.6656	0.2034	1.0293	0.0793	20.9875	0.0740	0.3567	22.0168
0.7824	0.1789	0.8682	0.0662	17.4108	0.0883	0.3334	18.2790

VIb: *EDAM cheese 45%. May 13, 2008.*

Strain	E_1 (MPa)	η_1 (MPas)	E_2 (MPa)	η_2 (MPas)	E_o (MPa)	$E_o+E_1+E_2$ (MPa)	$\eta_1+\eta_2$ (MPas)
0.8151	0.0396	0.3913	0.0228	7.2656	0.0107	0.0731	7.6568
0.8180	0.1000	0.4878	0.0381	9.6721	0.0209	0.1590	10.1599
0.8750	0.1444	0.6280	0.0580	15.1168	0.0301	0.2325	15.7449
0.5695	0.2801	1.4248	0.1138	28.9843	0.0677	0.4616	30.4091

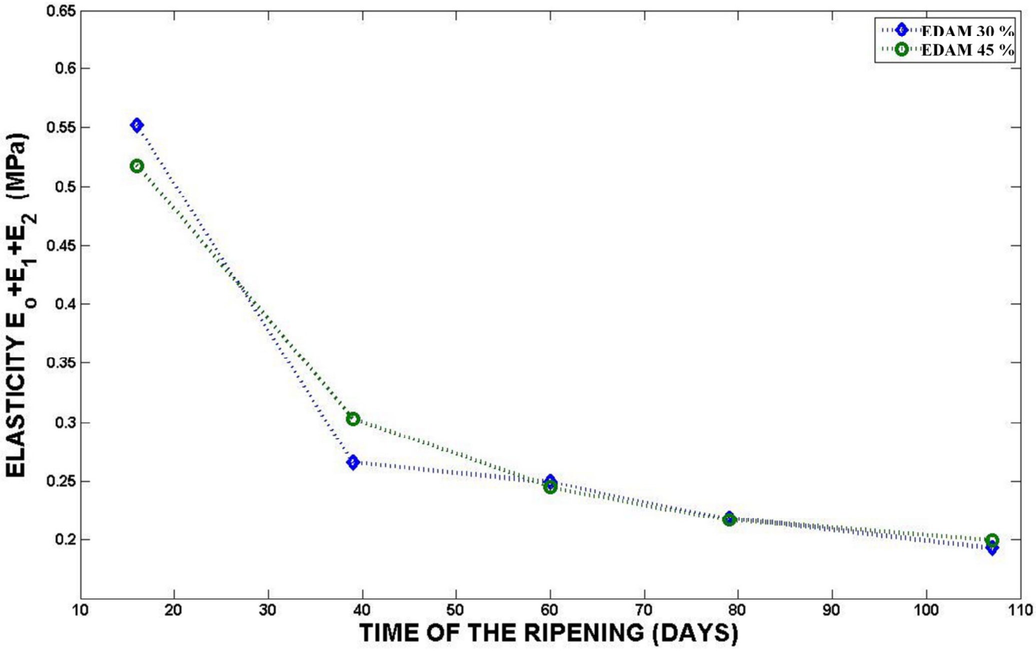


7: *Time history of the viscoelastic moduli*

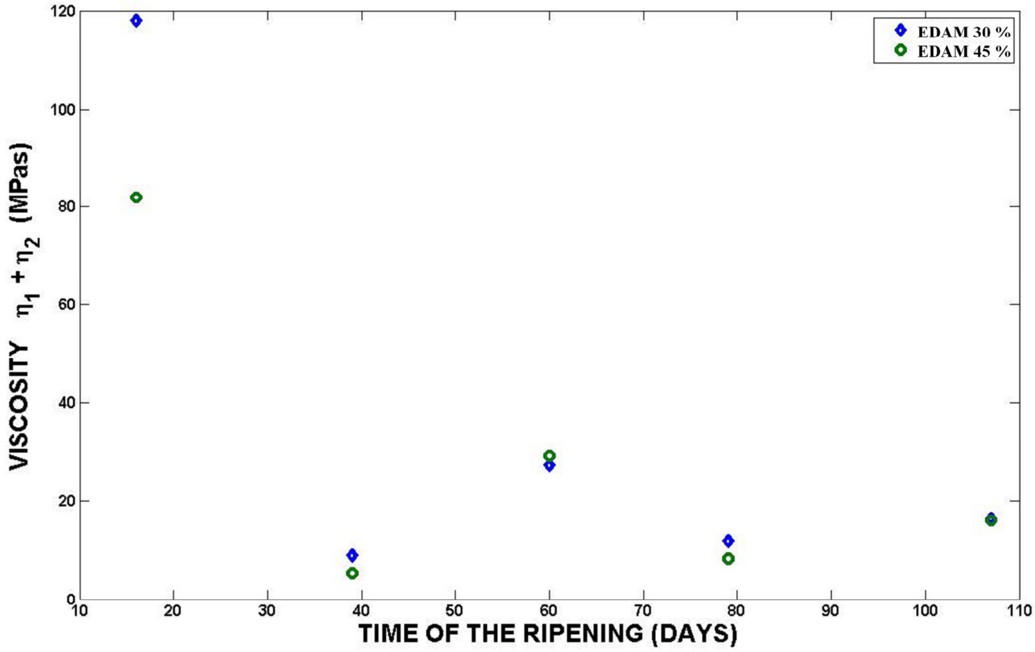


8: *The dependence of the viscoelastic modulus E(t) on the time of the cheese ripening*

In the Fig. 7 illustrates changes in the model values of viscoelastic modulus $E(t)$ (Eq. (4)) are illustrated. This Figure presents the courses obtained for different values of the initial strains. The totalled values of viscosity and damping were determined based on transformations of selected coefficients in the semi-empirical Maxwell model. It has been found that the courses of the viscoelastic moduli have not been



9: *Elasticity of the tested cheeses*



10: *Viscosity of the tested cheeses*

affected by the value of this parameter. It is evidence that the cheese behaves as linear viscoelastic solid.

The development of the viscoelastic modulus during the cheese ripening is displayed in the Fig. 8. If we compare Fig. 8 with the Fig. 5 one can see a difference. The relaxation curves shown in the Fig. 6 are less sensitive to the cheese maturity than the viscoelastic modulus. Viscoelastic moduli lie well above the moduli obtained from the stress – strain curves – see Eq. (9). The elasticity of the cheese given by the sum of moduli $E_o + E_1 + E_2$ decreases with the time of the ripening – see Fig. 9. There is very small if not negligible difference between cheeses with different fat content. This result is expected. The same tendency exhibits also the cheese viscosity, $(\eta_1 + \eta_2)$, see Fig. 10.

CONCLUSSIONS

The following results on the Edam cheese behaviour at mechanical behaviour have been obtained:

The response of the Edam cheese to the compression loading is sensitive to the loading rate. The level of the stress decreases with the increase in the fat content. Elastic moduli obtained from the compression test decrease with the time of the cheese ripening.

Relaxation tests show on the influence of the fat content and namely the time of the cheese ripening.

The evaluation of the relaxation tests has been performed in terms of the semi – empirical Maxwell model. The obtained results show that the tested cheeses behave like the linear viscoelastic body. Elasticity as well as the viscosity of the tested cheeses falls down during the cheese ripening. There is nearly no difference in the behaviour of cheeses with the different fat content.

Generally the results suggest that the relaxation test represent a simple and efficient tool for the evaluation of the constitutive equation of the tested cheeses. This equation can be than used in many commercially available numerical codes (ANSYS etc.). These codes enable to compute of the cheese response to general mechanical loading.

SOUHRN

Relaxace sil v sýru Eidamského typu během jeho zrání

V článku jsou uvedeny výsledky rozsáhlých zkoušek sýrů Eidamského typu se dvěma různými obsahy tuku (30 a 45 %) v průběhu jejich zrání. Zkoušky byly provedeny pomocí zkušebního zařízení TIRATEST v tlaku. Bylo použito několik rychlostí zatěžování. Ukazuje se, že tento parametr, stejně jako doba zrání a obsah tuku mají význačný vliv na průběh závislosti napětí – deformace vzorků zkoumaných sýrů. Vyhodnocené moduly pružnosti pak klesají se stupněm zralosti sýrů. Hlavní pozornost byla věnována relaxaci napětí, kdy vzorky jsou zatíženy do určitého stupně deformace a ta potom zůstává konstantní. Stanovený časový průběh síly představuje tzv. relaxační křivku, která popisuje míru elastického a viskózního chování zkoumaného materiálu. Výsledky získané v této práci byly interpretovány v rámci Maxwellova modelu, který umožňuje získat časovou závislost modulu pružnosti E(t). Ukazuje se, že zkoumané sýry se chovají jako lineárně vazkopružné těleso, což je typické chování pro řadu polymerů. Je ukázán výrazný vliv stupně zralosti sýru na velikost tohoto modulu. Elasticita a viskozita zkoumaných sýrů klesá s dobou jejich zrání a není výrazněji ovlivněna obsahem tuku. Ukazuje se, že použitá metoda umožňuje exaktní popis vlastností. Daný model, jehož parametry byly stanoveny, je použitelný v dalších komerčně dostupných programech, které umožňují numerickou simulaci veškerých možných silových účinků.

relaxace napětí, tlak, modul pružnosti, viskozita, Maxwellův model, zrání sýrů

SUMMARY

Paper involve results of a comprehensive tests which have been focused on the examination of the cheese behaviour at the compression loading and namely on the study of the relaxation properties. The experiments were carried out on blocks of Certified Origin EIDAM cheese (Eidamsky blok or Eidamska cihla in the Czech notation), manufactured by a company located in South Moravia. Cheeses with the fat content 30 and 45% have been tested. The pieces were matured in chambers where relative humidity and temperature were maintained according to the company procedures. Edam Cheese ripens under a ripening foil. The blocks of cheese have been tested at 16th (February 12, 2008), 39th (March 6, 2008), 60th (March 27, 2008), 79th (April 15, 2008), and 107th (May 13, 2008) day after the production. Cylindrical samples, 20.0 mm in diameter, were cut from cheese blocks using a cork-borer, and next they were cut into cylinders, 12.6 mm in height. Two basic experiments have been performed. The basic rheological properties are given by the uniaxial compression. Specimen of the cheeses has been compressed to about 70% deformation at different crosshead speeds (1 mm/min, 10 mm/min, 100 mm/min). The next rheological properties were determined with a relaxation test run also on TIRATEST testing machine. Each sample was compressed to different heights at the crosshead speed 10 mm/min. To each height corresponds some level of the loading force. The compression anvil was then held in position for 300 seconds to maintain a constant strain. It has been shown that the response of the Edam cheese to the compression loading was significantly sensitive to the loading rate. The level of the stress decreases with the increase in the fat content. Elastic moduli obtained from the compression test decreases with the time of the cheese ripening. This dependence may be taken as an evidence of the viscoelastic behaviour of the tested materials. These properties have been studied namely using of the relaxation tests. The evaluation of the relaxation tests has been performed in terms of the semi – empirical Maxwell model. The obtained results show that the tested cheeses behave like the linear viscoelastic body. Elasticity as well as the viscosity of the tested cheeses falls down

during the cheese ripening. There is nearly no difference in the behaviour of cheeses with the different fat content.

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