BEHAVIOUR OF PERGA UNDER COMPRESSIVE LOADING

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Abstract: The experimental testing of the perga cylinder samples at the compressive loading in the longitudinal direction was realized. The perga is bee product and it represents the material created from the bee pollen by means of the lactic fermetation. Mechanical properties such as the failure stress and strain as well as the modulus of elasticity can be used to evaluate the behaviour of the perga pellets mechanically under the static loading. A testing machine Andilog Stentor 1000 (Andilog Technologies, Vitrolles, France) was employed for compression tests. The samples of the perga have been tested at the different strain rates and the behaviour at the constant speed was compared with the behaviour at the different loading speeds. The experiments were performed at eighteen velocities from 10 to 270 mm.min^{-1} in order to achieve the different strain rates. The influence of strain rate on the stress was studied.

Keywords: compression loading, strain rate, modulus of elasticity, pollen bread

Introduction

Bee pollen is an interesting and promising product from beekeeping. It is a mixture of flower pollen and nectar with bee excreta. This bee product was characterized as the source of free amino acids, proteins, fats, fatty acids, mono- and polysaccharides, antioxidants, vitamins and pigments. Chemical and biochemical composition of bee pollen depends mainly on its botanical origin, but also on the time of harvesting, soil and climatic conditions. (Bleha et al. 2015). The term “bee bread” is reserved for the original bee pollen stored in the combs. The bee bread (or the perga) has already been processed by the bees for storage with the addition of various enzymes and honey, which subsequently ferments. This type of lactic acid fermentation is similar to that in yoghurts (and other fermented milk products) and renders the end product more digestible and enriched with new nutrients (Brindza et al. 2015). Bee bread is a product of the hive obtained from pollen collected by bees, to which they added honey and digestive enzymes and subsequently stored in the combs, starting a lactic fermentation which gives it greater power conservation (Zuluaga et al. 2015). The process of bee bread formative on starts with gathering of pollen, then a bee mixes it with flower nectar or honey and saliva, and carries to the beehive, where non flying bees fill the mixture into honey comb cells for the three quarters of the cell volume. An anaerobic lactic fermentation process takes place and bee bread is forming. Bee bread differs from pollen by lower pH (3.8–4.3), it contains less proteins and fats, but more carbohydrates and lactic acid (Mizrahi and Lensky 2012). The compressive properties of the perga are very rare. We interested with the uniaxial compressive test of the perga samples. Severa (2008) interested with the compression test of the fruits at the different strain rates which corresponded to the quasi – state loading. If the material exhibits viscoelastic behavior a Maxwell model with increasing modulus of elasticity can be considered as a simple so called explanatory model, which can explain the stress – strain curves (Csima et al. 2014). Extensive test have shown that if the initial part of force-deformation curves of soft biological tissues are taken into consideration, the initial part of the curves are usually concaved towards the force axis. This is exactly opposite the force-deformation curves for polymeric materials which is usually convex towards the force axis (Mohsenin 1986). Sarvari and Malinen (2006) interested with the numerical method for computing the relaxation modulus of a linearly viscoelastic material. The method is valid for relaxation tests where a constant strain rate is followed by a constant strain.

The objectives of the study were aimed on the study of the perga cylinder samples. The samples of the perga have been tested at the different strain rates and the behaviour at the constant speed was compared with the behaviour at the different loading speeds. The experiments were performed at eighteen velocities from the 10 to 270 mm.min^{-1} in order to achieve the different strain rates. The influence of strain rate on the stress was studied. The moduli of elasticity were determined on the base of elastic Hook's theory.

Material and Methods

The samples of the perga from the different sorts of the plants were collected from the selected regions of Ukraine (Poltava and Dnepropetrovsk) and were taken from the combs by the new method developed and patented by the Ukraine authors of the paper. All samples of the perga were polyfloral. The samples had the cylindrical shape which was given by the shape of the comb cells. The perga was stored permanently at the temperature 4°C – 6°C and the air humidity (40 – 60) % in the refrigerator. The moisture of the perga samples was 14 %.

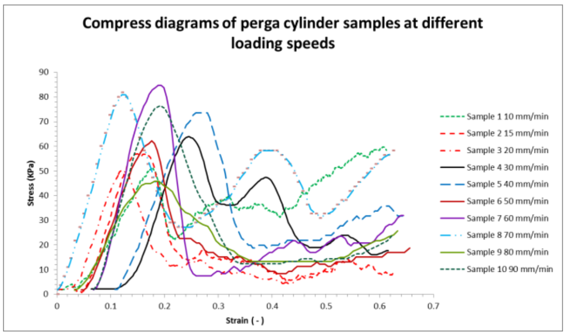
Statical compressive loading in the uniaxial direction was used for the perga samples testing. A testing machine Andilog Stentor 1000 (Andilog Technologies, Vitrolles, France) was employed for compression tests. The compression of perga samples between two parallel plates was realized (Fig. 1).

Figure 1 Compression of perga sample between two parallel plates

The experiments were performed at eighteen velocities from the 10 to 270 $mm.min^{-1}$ in order to achieve the different strain rates. The influence of strain rate on the stress was studied.The experiments were also realized at the loading speed 10 $mm.min^{-1}$for ten samples of the perga.The aim was to test the variability of measurements between the 18 different loading speeds with one sample and one speed for ten samples.The force F (N) and the compression D (m) were measured by the acquisition software RSIC ver. 4.06. The stresses and the strains were calculated as the rates of the mesured forces and the compressions by means of the sections and the length of the cylindrical samples. The loading curves of dependence of the stress on the strain were realized. The method based on the elastic theory and the Hook's law was used for determination of the moduli of elasticity. Values of moduli of elasticity were calculated as the slope of the linear part of the stress – strain curves on the base of regression method. The maximal values of the strain and the stress were determined from the maximums of the loading curves.

Results

The dependences of the stress on the strain, for first ten samples, when the loading speeds ranged from 10 $mm.min^{-1}$ to 90 $mm.min^{-1}$ are shown in Fig. 2 and when the loading speeds ranged from 100 $mm.min^{-1}$ to 270 $mm.min^{-1}$ are shown in Fig. 4. The influence of the loading speeds on the stresses during the compression between two parallel plates are presented. The influence of the loading rate on the stress during compression was very small and unregular.The stress – strain curves were characterized by the peaks which reprezent the limit of the firmness of the cylinder perga samples.The parameters of the samples as loading speeds, strain rates, values of strains and stresses in the maximum of the compress curves and the moduli of elasticity are outlined in Table 1 and Table 2. Determination of the moduli of elaticity as the slopes of the linear parts of the curves are presented in the Fig. 3 and Fig. 5 for two groups of loading speeds from the Fig. 2 and Fig. 4.



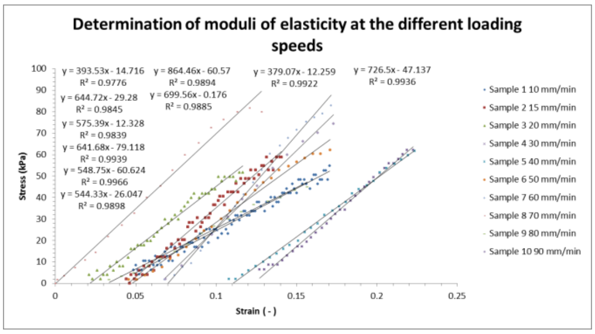


Figure 2 The influence of the loading speeds (from 10 $mm.min^{-1}$ to 90 $mm.min^{-1}$) on the stresses during the perga compression between two parallel plates

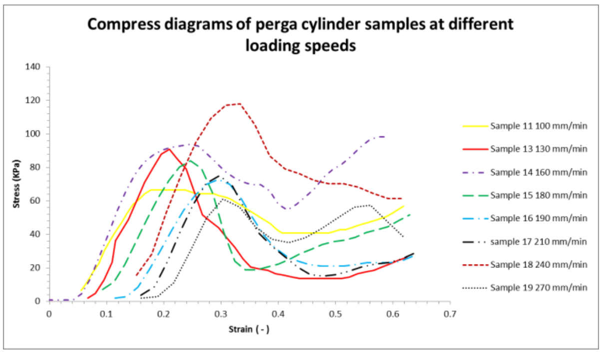
Figure 3 Determination of the moduli of elasticity from the slopes of the linear parts of the stress – strain curves (loading speeds from 10 $mm.min^{-1}$ to 90 $mm.min^{-1}$)

Table 1 Parameters of the perga cylinder samples.v – loading speed, d – diameter of the sample, l – length of the sample, S – cross – section of the sample, ε_m – strain in maximum, σ_m – stress in maximum, E – modulus of elasticity, SD – standard deviation

Sample	v ($mm.min^{-1}$)	Strain rate (s^{-1})	d (mm)	l (mm)	S (mm^{-2})	ε_m (-)	σ_m (kPa)	E (kPa)
1	10	0.020	5.25	8.20	21.64	0.17	52.70	393.53
2	15	0.025	5.35	9.95	22.47	0.16	56.75	644.72
3	20	0.034	5.40	9.95	22.89	0.11	49.72	575.39
4	30	0.047	5.20	10.55	21.23	0.23	62.19	641.68
5	40	0.068	5.40	9.80	22.89	0.26	73.61	548.75
6	50	0.083	5.55	10.05	24.18	0.18	60.26	544.33
7	60	0.086	5.55	11.60	24.18	0.19	84.74	864.46
8	70	0.127	5.65	9.20	25.06	0.12	81.77	699,56
9	80	0.131	5.90	10.20	27.33	0.17	44.98	379.07
10	90	0.149	5.30	10.05	22.05	0.18	74.42	726.50
Mean		0.077	5.455	9.955	23.391	0.177	64.111	590.937
SD		0.015	0.067	0.275	0.581	0.014	4.359	48.310
Coeff. of variance (%)		19.090	1.226	2.764	2.486	7.792	6.799	8.175

The influence of the strain rates and loading speeds were confirmed on the stresses and the strains in the maximum of the stress – strain curves, it means on the firmness of the perga samples by means of correlation method showed in the Table 3. The good correlation was also confirmed between moduli of elasticity and the stresses in the maximum. Another correlations were not confirmed. The firmness of the perga cylinder samples at the loading speed ranged from 10 to 270 $mm.min^{-1}$ ranged for the strains in maximum from 0.11 to 0.31 and for the stresses in the maximum from 44.98 kPa to 119.14 kPa. The moduli of elasticity at the loading speed ranged from 10 to 270 $mm.min^{-1}$ ranged from 379.07 kPa to 964.16 kPa.

The measurement of the ten samples of the perga was realized also at the same loading speed 10 $mm.min^{-1}$. The aim was to test the variability of the results. The stress – strain curves are presented in the Fig. 6. The determination of the moduli of elasticity from the slopes of the stress – strain curves is showed in Fig 7. The obtained parameters are presented in the Table 4. The firmness of the perga cylinder samples is presented by the mean values strain in maximum ε_m=(0.194±0.021) and by the mean values of the stress in the maximum



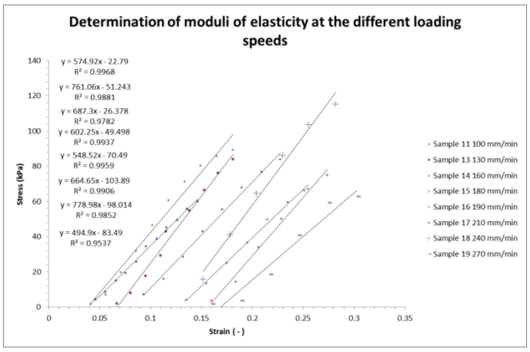


Figure 4 The influence of the loading speeds (from 100 $mm.min^{-1}$ to 270 $mm.min^{-1}$) on the stresses during the perga compression between two parallel plates

Figure 5 Determination of the moduli of elasticity from the slopes of the linear parts of the stress – strain curves (loading speeds from 100 $mm.min^{-1}$ to 270 $mm.min^{-1}$)

Table 2 Parameters of the perga cylinder samples.v – loading speed, d – diameter of the sample, l – length of the sample, S – cross – section of the sample, ε_m – strain in maximum, σ_m – stress in maximum, E – modulus of elasticity, SD – standard deviation

Sample	v ($mm.min^{-1}$)	Strain rate (s^{-1})	d (mm)	l (mm)	S (mm^{-2})	ε_m (-)	σ_m (kPa)	E (kPa)
11	100	0.159	5.20	10.45	21.23	0.18	62.16	574.92
13	130	0.227	5.45	9.55	23.32	0.20	91.78	761.06
14	160	0.249	5.70	10.70	25.50	0.21	92.85	687.30
15	180	0.305	5.70	9.85	25.50	0.23	83.91	602.25
16	190	0.317	5.50	10.00	23.75	0.28	72.85	548.52
17	210	0.359	5.70	9.75	25.50	0.27	75.01	664.65
18	240	0.410	5.45	9.75	23.32	0.31	119.14	778.98
19	270	0.455	5.60	9.90	24.62	0.30	62.88	494.90
Mean		0.310	5.538	9.994	24.092	0.247	82.572	639.073
SD		0.035	0.062	0.137	0.531	0.018	6.662	35.830
Coeff. of variance (%)		11.128	1.116	1.372	2.205	7.170	8.068	5.607

Table 3 Correlation between measured parameters for all loading speeds. v – loading speed, d – diameter of the sample, l – length of the sample, S – cross – section of the sample, ε_m – strain in maximum, σ_m – stress in maximum, E – modulus of elasticity

	v ($mm.min^{-1}$)	Strain rate (s^{-1})	d (mm)	l (mm)	S (mm^{-2})	ε_m (-)	σ_m (kPa)	E (kPa)
v ($mm.min^{-1}$)	1							
Strain rate (s^{-1})	0.999	1						
d (mm)	0.423	0.418	1					
l (mm)				1				
S (mm^{-2})	0.418	0.412	1.000		1			
ε_m (-)	0.770	0.769				1		
σ_m (kPa)	0.545	0.545				0.451556	1	
E (kPa)				0.436			0.740167	1

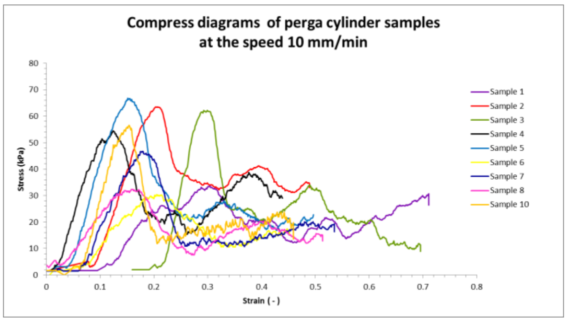
σ_m=(50.192±4.766) kPa. The elasticity of the perga samples is presented by the mean value of the modulus of elasticity E=(474.604±68.515) kPa.

The influence of the strain rate on the stress is shown in the Figs. 8 and 9. The dependences were calculated for the strains of 0.2 and 0.3 respectively. The coefficients of the determination are low 0.0236 for Fig. 8 and 0.5217 for Fig 9. It means the coefficients of the correlation are 0.1536 for Fig. 8 and 0.7223 for Fig 9. The material exhibits a typical linear viscoelastic behavior. The Kelvin model of viscoelasticity is described by the equation:

$$\sigma = E\varepsilon + \eta\dot{\varepsilon} \qquad (1)$$

where: η is the dynamic viscosity, Pa.s

$\dot{\varepsilon}$ is the strain rate, s^{-1}



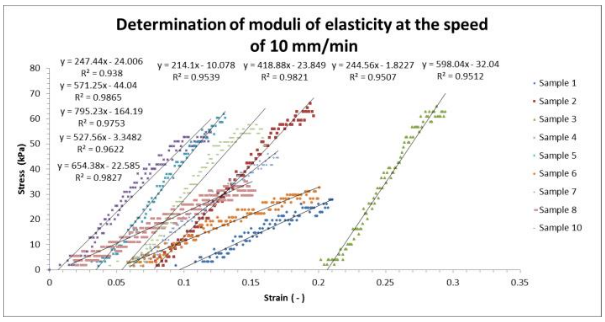
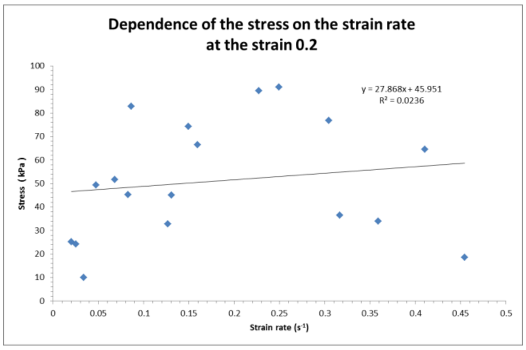


Figure 6 The influence of the loading speed 10 mm.min^{-1} on the stresses during the perga compression between two parallel plates

Figure 7 Determination of the moduli of elasticity from the slopes of the linear parts of the stress – strain curves (loading speed 10 mm.min^{-1})

Table 4 Parameters of the perga cylinder samples.v – loading speed, d – diameter of the sample, l – length of the sample, S – cross – section of the sample, ε_m – strain in maximum, σ_m – stress in maximum, E – modulus of elasticity, SD – standard deviation

Sample	v (mm.m^{-1})	d (mm)	l (mm)	S (mm^{-2})	ε_m (-)	σ_m (kPa)	E (kPa)
1	10	5.95	9.45	27.79	0.30	34.40	247.44
2	10	5.85	8.85	26.86	0.20	64.40	571.25
3	10	5.35	10.90	22.47	0.29	62.84	795.23
4	10	5.65	10.90	25.06	0.12	54.51	527.56
5	10	6.05	9.85	28.73	0.15	68.15	654.38
6	10	6.25	10.45	30.66	0.21	31.18	214.10
7	10	6.25	9.70	30.66	0.17	47.52	418.88
8	10	5.60	9.95	24.62	0.15	33.27	244.56
10	10	5.85	10.45	26.86	0.15	55.47	598.04
Mean		5.867	10.056	27.081	0.194	50.192	474.604
SD		0.100	0.228	0.916	0.021	4.766	68.515
Coeff. of variance (%)		1.705	2.266	3.383	10.907	9.495	14.436



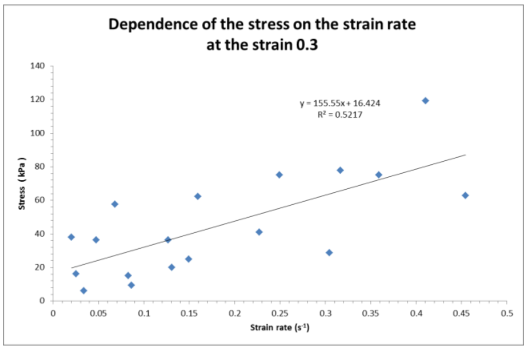


Figure 8 Strain rate influence on the stress at the strain 0.2

Figure 9 Strain rate influence on the stress at the strain 0.3

When we applied the regression equations from the Figs. 8 and 9 we obtained from the slopes the dynamic viscosity of the perga samples 27.868 kPa.s at the strain 0.2 and 155.55 kPa.s at the strain 0.3.

Discussion

Compression test of the perga at the different strain rates corresponds to the quasi – state loading. The influence of the loading rate on the stress during compression was very small and unregular. The mean values of the parameters, excepting diameter, length and cross – section, from the Tables 1 and 2 were calculated at the different loading speeds of the samples, so they did not represent the data of the good structure. But the influence of the loading speed on the parameters from the Tables 1 and 2 was comparable with the influence of the constat loading speed presented in the Table 4, where the data of the good structure are presented – loading at the constant speed. The variability of the measured parameters during different loading speeds is presented by the standard deviation. The standard deviations for the all parameters from the Tables 1, 2 and 4 are comparable. It means that the measurements at the 18 loading speeds were almost identical with the measurements at the one constant speed. Liu and Zhang (2004) interested with determination of mechanical properties of pollen grains.The mean rupture force was 1.20 ± 0.03 mN, and mean deformation at rupture was 22 ± 0.6%. A constitutive equation based on Hookean law was used to determine the mechanical property parameters Eh (rate of modulus of elasticity and the wall thickness) of desiccated pollen grains as 1653 ± 36 N/m.

Conclusions

The loading curves of dependence of the stress on the strain were realized. The influence of the strain rates and loading speeds were confirmed on the stresses and the strains in the maximum of the stress – strain curves, it means on the firmness of the perga samples. The good correlation was also confirmed between moduli of elasticity and the stresses in the maximum. Another correlations were not confirmed. Strain rate influence on the stress calculated for the strains of 0.2 and 0.3 respectively was confirmed by the regression model with the coefficients of the correlation 0.1536 and 0.7223 respectively.The dynamic viscosity of 27.868 kPa.s at the strain 0.2 and 155.55 kPa.s at the strain 0.3 of the perga samples were determined. The firmness of the perga cylinder samples at the loading speed ranged from 10 to 270 mm.min^{-1} ranged for the strains in maximum from 0.11 to 0.31 and for the stresses in the maximum from 44.98 kPa to 119.14 kPa. The moduli of elasticity at the loading speed ranged from 10 to 270 mm.min^{-1} ranged from 379.07 kPa to 964.16 kPa. The firmness of the perga cylinder samples at the loading speed 10 mm.min^{-1} was presented by the mean values strain in maximum ε_m=(0.194±0.021) and by the mean values of the stress in the maximum σ_m=(50.192±4.766) kPa. The elasticity of the perga samples was presented by the mean value of the modulus of elasticity E=(474.604±68.515) kPa.

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