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MECHANICAL BEHAVIOUR OF OSTRICH'S EGGSHELL AT COMPRESSION

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Abstract

NEDOMOVÁ ŠÁRKA, BUCHAR JAROSLAV, STRNKOVÁ JANA: *Mechanical behaviour of Ostrich's eggshell at compression.* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 2013, LXI, No. 3, pp. 729–734

The deformation and fracture behaviour of Ostrich's eggs at the static compression has been investigated. The mechanical properties of egg to compression were determined in terms of average rupture force, specific deformation and rupture energy along X and Z axes. Exact description of the eggshell counter shape has been used for the verification of a common accepted theory of the compression of bodies of convex form. The eggshell strength seems to be an unique function of the static stiffness. The greatest amount of force required to break the eggs was required when eggs were loaded along the X axis and the least compression force was required along the Z axis. The specific deformation and rupture energy required for the eggs tested was lower along the X axis than the Z axis. The highest measure of firmness in the eggs tested was found to be along their X axis. Young's modulus of the elasticity, *E*, has been also evaluated. Its value is independent on the direction of the egg compression. The value of *E* is approximately two times higher that of the chicken eggs.

strength, modulus of elasticity, eggshell stiffness, rupture force

The function of the eggshell is to protect the contents of the egg from mechanical impacts and microbial contamination (e.g. *Salmonella*) and to control the exchange of water and gases through the pores. Egg is a packaged food and an important quality aspect of the packaged egg material is the mechanical strength of the eggshell. A commonly used technique for the measurement of the shell strength is the quasi-static, non-destructive compression of an egg between two parallel steel plates (Coucke *et al*,. 1998; De Ketelaere *et al*., 2002). Number of papers devoted to the mechanical behaviour of Ostrich eggs is limited (Ross *et al*., 2009). Most of the papers focused on the problem of the shell strength deals namely with the chicken eggs. Resistance of the eggshell to damage through mechanical loading is than characterized by measures such as rupture force, specific deformation and rupture energy (Voisey and Hunt, 1969; Abdallah *et al*., 1993; Altuntas and Sekeroglu, 2008). The rupture force of hen eggs depended on various egg properties such as egg specific gravity, egg mass, egg volume, egg surface area, egg thickness, shell weight, and shell percentage (Narushin *et al*., 2004). The strongest correlation was found between shell rupture force breaking strength is correlated with shape index (Carter, 1976). Breaking strength as a direct variable to measure of eggshell strength, is a difficult variable to measure, because only one measurement can be taken from each egg, and is highly dependent on compression speed (Voisey and Hunt, 1969). However, there is a paucity of technical information and data in the scientific literature with regards to the mechanical behaviour of chicken eggs under different compression orientations.

The objective of this study was to investigate the effect of the compression orientation on the mechanical properties of Ostrich eggs. The mechanical properties examined were rupture force, specific deformation, rupture energy and firmness.

MATERIAL AND EXPERIMENTAL METHOD

Eggs were collected from a commercial packing station. The main characteristics of the eggs have been evaluated: mass, the egg length, L and the egg width, W. These data are presented in the Tab. I. The eggshell shape has been described using of the shape index (SI) which is defined as

$$SI = \frac{W}{L} \times 100 . \qquad (1)$$

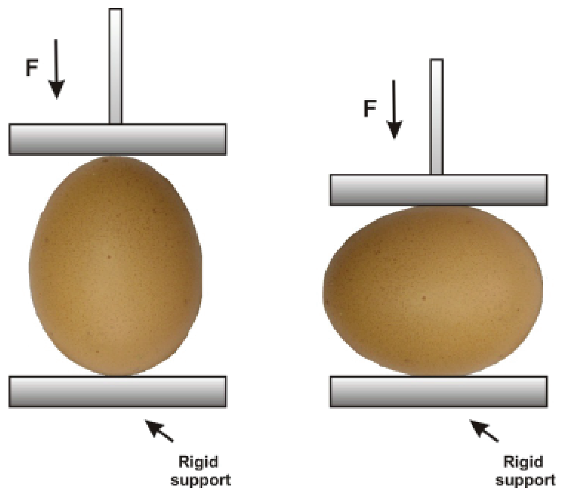
I: *Main parameters of the tested eggs*

Egg No	Mass m [kg]	Length L [mm]	Width W [mm]
1	1.20	137.86	116.11
2	1.35	146.10	122.29
3	1.15	137.15	115.62
4	1.55	166.64	124.11
5	1.45	139.16	124.86
6	1.50	161.65	123.39
7	1.50	149.99	123.28
8	1.35	142.15	120.70
9	1.30	142.81	119.11
10	1.20	142.31	116.13

The eggshell counter shape has been described in our previous paper (Nedomová and Buchar, 2013).

The eggs have been compressed between the two plates using testing device TIRATEST. The egg sample was placed on the fixed plate and loaded at the compression speed 0.33 mm.s^{-1} and pressed with a moving plate connected to the load cell.

The eggs have been loaded along two compression axes shown in the Fig. 1.



1: *Schematic of the eggs compression. On the left side the egg is compressed along the X axis (between poles). The compression along the Z axis (in equator plane) is shown in the right side.*

The experiments have been performed in two steps. First of all the eggshell stiffness has been evaluated. The egg is placed horizontally between two parallel steel plates and a force of 100 N is exerted on the object. The force, F – displacement, x curve is registered and the slope of this curve is used for the assessment of a static stiffness parameter (k_s) which is defined as:

$$k_s = \left(\frac{dF}{dx} \right)_{x=0} . \qquad (2)$$

This parameter can be used for a relatively exact estimation of the eggshell strength of chicken eggs (Anderson *et al.*, 2004).

During the destructive experiments eggs have been compressed until the egg ruptured. The evaluation of these experiment sis well described e.g. by Nedomová *et al.* (2009).

RESULTS AND DISCUSSION

The non-destructive loading of the eggs shows that the dependence of the loading force, F on the displacement x is linear:

$$F = kx + q, \qquad (3)$$

where parameters k and q are given in the Tab. II.

II: *Results of the non-destructive tests. (R^2 – coefficient of determination)*

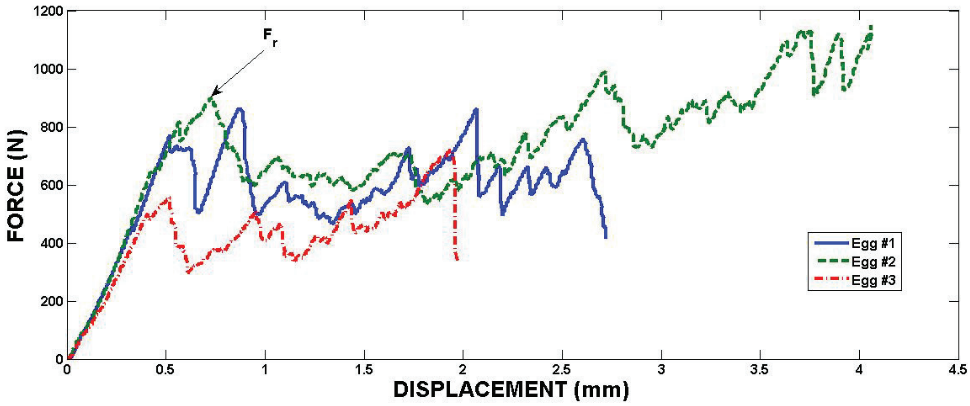
Loading axis	Egg No	k [N.mm^{-1}]	q [N]	R^2
X	1	1266.7	4.3	0.9351
	2	1484.3	2.8	0.986
	3	932.5	3.7	0.9341
Z	4	928.4	5.2	0.9528
	5	1054.2	4.6	0.9746
	6	1012.4	4.1	0.9423

Eggshell stiffness is given by the parameter k in the Eq. (3). It is obvious that the eggshell stiffness is higher for eggs loaded along the X axis (between poles of the eggs) than for the egg loaded along the Z axis (in equator plane).

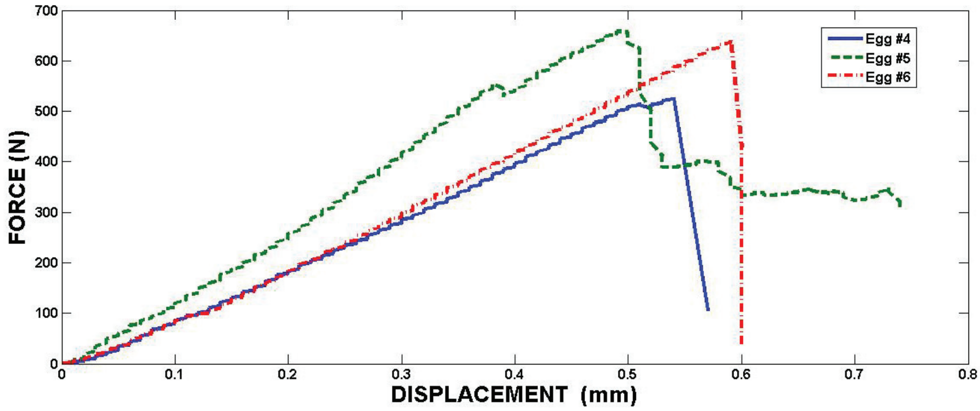
In the Fig. 2 the experimental records of the force F– displacement x obtained for eggs loaded along the X axis are displayed. One can see that the loading force increases to some maximum following by many oscillations. The eggshell is damaged by many radial cracks at the area of contact of the eggshell and moving plate. The first maximum has been taken as the rupture force, F_r.

Energy absorbed (E_a) by an egg at the moment of rupture was determined by calculating the area under the force–deformation curve from the following equation:

$$E_a = \int_0^{x_m} F dx . \qquad (4)$$



2: *Experimental records of the eggs loading along the X axis (between poles)*



3: *Experimental records of the eggs loading along the Z axis (in the equator plane)*

III: *Experimental results of the destructive loading*

Loading axis	Egg No	x_m [mm]	F_r [N]	E_a [Nmm]	E_f [Nmm]	E_f - E_a [Nmm]	Q [N.mm^{-1}]
X	1	0.52	771.73	109.15	921.81	812.66	1484.1
	2	0.74	904.54	217.19	1781.85	1564.67	1222.4
	3	0.53	559.07	90.59	497.19	406.61	1054.8
Z	4	0.57	531.52	90.69	91.35	0.66	932.5
	5	0.53	670.85	101.54	159.88	58.34	1265.8
	6	0.61	643.3	109.91	111.47	1.57	1054.6

where x_m is the eggshell displacement at the point of rupture on the egg.

The force oscillations probably correspond to cracks propagation through the eggshell thickness. If the cracks achieved the interface between the eggshell and membranes the force is falling down. The extent of the cracking area can be characterized by an energy E_c:

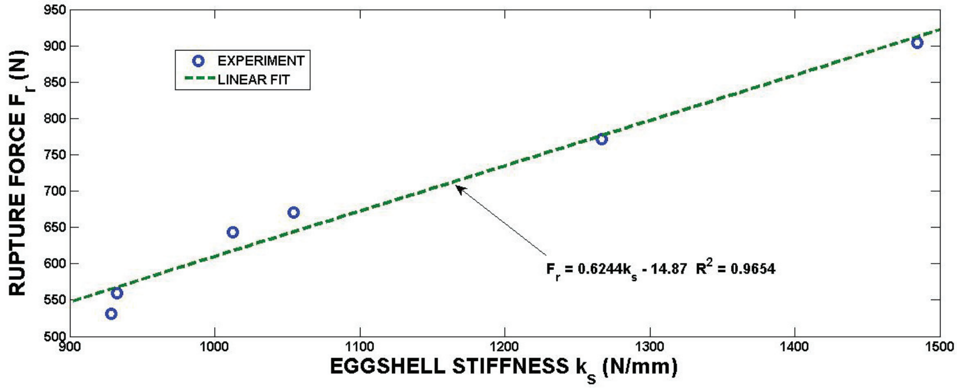
$$E_c = E_f - E_a \qquad E_f = \int_0^{x_f} F dx\,, \tag{5}$$

where x_f is the final displacement of the eggshell.

Firmness is regarded as a ratio of compressive force to displacement at the rupture point of an egg. The firmness was obtained from the following equation:

$$Q = \frac{F_r}{x_m}. \tag{6}$$

The experimental records of the force F – displacement *x* obtained for eggs loaded along the Z axis are displayed in the Fig. 3. There is a remarkable difference between curves reported in the Fig. 2 and Fig. 3. Under compressive loading along the Z axis, eggs deform in an essentially linear elastic manner until the maximum load when an abrupt load drop. The damage of the eggshell is characterized by one macroscopic crack which extends from the load point nearly to the egg poles.



4: *Eggshell rupture force vs. eggshell stiffness*

The values of quantities describing the fracture of the eggs are given in the Tab. III.

In the Fig. 4 the dependence of the rupture force on the eggshell stiffness is displayed.

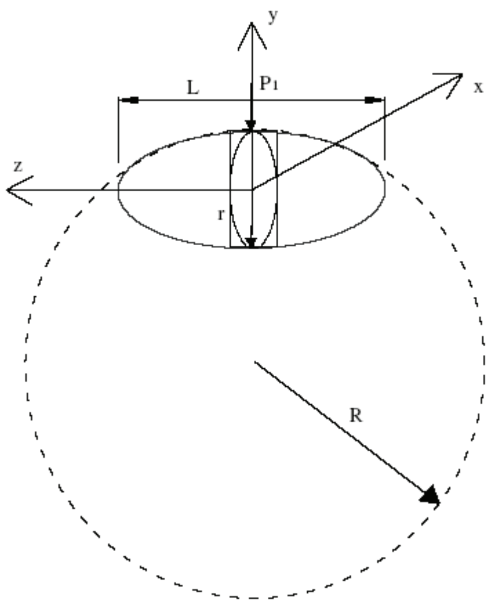
Results show that the rupture forces can be estimated using of the eggshell stiffness like as for the chicken eggs. The dependence of other parameters given in the Table III on the eggshell stiffness is not too clear. It may be a consequence of limited number of experimental data. Some additional experiments are urgently needed.

The deformation behaviour of the eggshell is assumed to be elastic. If we consider the elastic strain as isotropic and linear the elastic properties are described by the Young's modulus *E* and by the Poisson's ratioν. The modulus of elasticity is evaluated from the following equation (ASAE, 2001):

$$E = \frac{0.531F\left(1-\nu^2\right)}{x^{\frac{3}{2}}}\left[2\left(\frac{1}{R}+\frac{1}{r}\right)^{\frac{1}{3}}\right]^{\frac{3}{2}}. \tag{7}$$

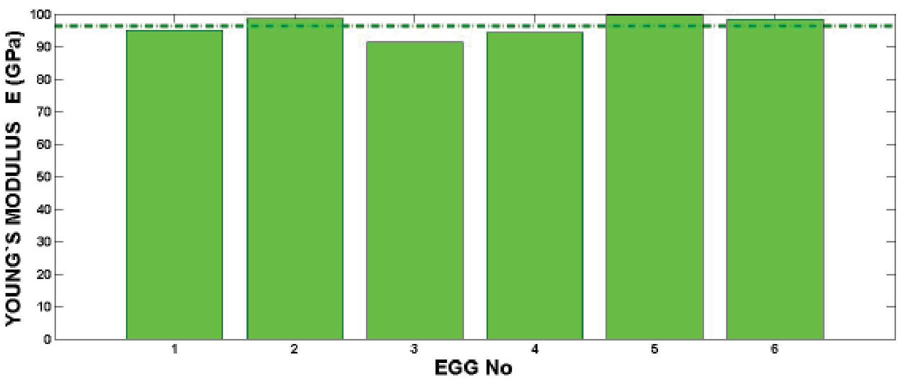
The meaning of the radii R and r is illustrated in the Fig. 5.

The radii of the eggshell curvature have been determined in our previous paper (Nedomová and Buchar, 2013).



5: *Radii of the curvature of the eggshell curve*

The computation has been performed for the force F = 50 N and corresponding displacement x. The force is significantly lower than the rupture



6: *Modulus of elasticity of the tested eggs* force. Owing to the linear dependence F = F(x) the corresponding displacement is also lower than that at the rupture point. It means the radii of the curvature, *R*, *r*, obtained for the undeformed egg can be used. The parameter ν has been taken as 0.35. This value is typical for the many shells (Mayers *et al.*, 2008). The values of E obtained from Eq. (7) are shown in the Fig. 6.

The value of E is probably independent on the loading orientation. Its average value is higher than that found for the chicken eggs (McLeod *et al.*, 2006) by factor two at least.

CONCLUSIONS

Results obtained in the given paper suggest that the rupture force of the eggshell and other quantities connected with the eggshell damage (displacement at the eggshell rupture, specific deformation, energy absorbed during deformation and firmness) depends on the orientation of the loading force during eggs compression. It means the qualitative features of the ostrich's eggs behaviour under quasistatic compression is the same as for the chicken and quail eggs. Contrary to the chicken and quail eggs the ostrich's eggs exhibit significant difference in the damage development during the compression at different orientation of the loading.

The values of the rupture force can be very effectively predicted using of the eggshell stiffness. The values of the modulus of the elasticity, E, describing the strain behaviour of the eggshell have been found. This modulus is independent on the loading force orientation. These results support the hypothesis that the eggshell exhibits elastic behaviour up to the eggshell rupture.

SUMMARY

In the given paper the results on the mechanical behaviour of the Ostrich's eggs under quasi static compression between two plates are presented. Experiments have been performed in two steps.

First of all the eggshell stiffness has been evaluated. The egg is placed horizontally between two parallel steel plates and a force of 100 N is exerted on the object. The force, F – displacement, x curve is registered and the slope of this curve is used for the assessment of a static stiffness parameter (k_s). It has been found that the eggshell stiffness is higher for eggs loaded along the X axis (between poles of the eggs) than for the egg loaded along the Z axis (in equator plane).

In the next step eggs have been loaded up to the fracture. The experimental records of the loading force *vs.* plate displacement are different for the different orientation of the egg loading. This phenomenon is a consequence of the different mechanisms of the eggshell damage. The rupture force depends on the orientation of the loading force during eggs compression. It means the qualitative features of the ostrich's eggs behaviour under quasistatic compression is the same as for the chicken and quail eggs. The values of the rupture force can be very effectively predicted using of the eggshell stiffness. The dependence of other quantities connected with the eggshell damage (displacement at the eggshell rupture, specific deformation, energy absorbed during deformation and firmness) on the orientation is not too clear. It may be a consequence of a limited number of the tested eggs.

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REFERENCES

ABDALLAH, A. G., HARMS, R. H., EL-HUSSEINY, O., 1993: Various methods of measuring shell quality in relation to percentage of cracked eggs. *Poultry Sci*, 72, 11: 2038–2043. ISSN 0032-5791.

ALTUNTAS, E., SEKEROG LU, A., 2008: Effect of egg shape index on mechanical properties of chicken eggs. *J Food Eng*, 85, 4: 606–612. ISSN 0260-8774.

CARTER, T. C., 1976: The hen's egg: shell forces at impact and quasi-static compression. *Brit Poultry Sci*, 17, 2: 199–214. ISSN 0007-1668.

COOPER, R. G., LUKASZEWICZ, M., HORBANCZUK, O. J., 2009: The Ostrich (*Struthio camelus*) Egg – a Safety Seat in the Time Vehicle. *Turk J Vet Anim Sci*, 33, 1: 77–80. ISSN 1300-0128.

COUCKE, P., JACOBS, G., SAS, P., DE BAERDEMAEKER, J., 1998: Comparative analysis of the static and dynamic mechanical eggshell behaviour of a chicken egg. In: *International Conference on Noise and Vibration Engineering (ISMA 23, September 1998)*. Lueven: Katholieke Universiteit Leuven, 1497–1502.

DE KETELAERE, B., GOVAERTS, T., COUKE, P., DEWIL, E., VISSCHER, T., DECUYPERE, E., De BAERDEMAEKER, J., 2002: Measuring the eggshell strength of 6 different strains of laying hens: Techniques and comparison. *Brit Poultry Sci*, 43, 2: 238–244. ISSN 0007-1668.

MACLEOD, N., BAIN, M.M., HANCOCK, J.W., 2006: The mechanics and mechanisms of failure of hens' eggs. *Int J Fracture*, 142, 1: 29–41. ISSN 0376-9429.

MEYERS, M. A., CHEN, P. Y., LIN, A. Y. M., SEKI, Y., 2008: Biological Materials: Structure and

Mechanical Properties. *Prog Mater Sci*, 53, 1: 1–206. ISSN 0079-6425.

NARUSHIN, V. G., van KEPMEN, T. A., WINELAND, M. J., CHRISTENSEN, V. L., 2004: Comparing infrared spectroscopy and egg size measurements for predicting eggshell quality. *Biosyst Eng*, 87, 3: 367–373. ISSN 1537-5110.

NEDOMOVÁ, Š., BUCHAR, J., 2013: Ostrich eggs geometry. Submitted to *Acta univ.agric et silvic. Mendel. Brunen.,* 61, 3: 735-742. ISSN 1211-8516.

NEDOMOVÁ, Š., SEVERA, L., BUCHAR, J., 2009: Influence of hen egg shape on eggshell compressive strength. *Int Agrophys*, 23, 3: 249–256. ISSN 0236-8722.

VOISEY, P. W., HUNT, J. R., 1969: Effect of compression speed on the behaviour of eggshells. *J Agr Eng Res,* 14, 1: 40–46. ISSN 1095-9246.

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