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GOOSE`S EGGSHELL STRENGTH AT COMPRESSIVE LOADING

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ABSTRACT

The paper deals with the study of the goose eggs behaviour under compressive loading between two plates using testing device TIRATEST. The influences of the loading orientation as well as the effect of compressive velocity are studied. 226 eggs from *Landes* geese were chosen for the experiment. Eggs have been loaded between their poles and in the equator plane. Five different compressive velocities (0.0167, 0.167, 0.334, 1.67 and 5 mm.s^{-1}) were used. The increase in rupture force with loading rate was observed for loading in all direction (along main axes). Dependence of the rupture force on loading rate was quantifies and described. The highest rupture force was obtained when the eggs were loaded along their axes of symmetry (X-axis). Compression in the equator plane (along the Z-axis) required the least compressive force to break the eggshells. The eggshell strength was described by the rupture force, specific rupture deformation and by the absorbed energy. The rupture force is highly dependent on compression speeds. The dependence of the rupture force on the compression velocity can be described by a power function. The same is valid for the rate dependence of the energy absorbed by the egg up to the fracture. The rate sensitivity of the Goose`s eggshells strength is significantly higher than that reported for the hen`s eggs.

Keywords: goose’s egg; compressive velocity; ruptures force; deformation; absorbed energy

INTRODUCTION

Eggs can be regarded as naturally packaged food. When examining the quality of the packaging, one primarily considers the strength of the eggshell. For table eggs, shells must be strong enough to prevent failure during packing and/or transportation. For hatching eggs, shells have to be thick and strong for preservation of the embryo as well as thin for gas exchange and weak enough to allow the chick to crack the shell when hatching **(Narushin and Romanov, 2002)**. Except common eggs (hens, quails) are also consumed waterfowls eggs producing by small-scale farmers and in Asian countries.

Resulting eggshell strength is influenced by material and structural strength **(Bain, 1992)**. The material strength depends on the association of the mineral and the organic components of the shell. **Fraser et al. (1998)** mentioned that the organic matrix is considered to play a role in the regulation of various stages of crystal growth (i.e., the deposition of calcium carbonate on organic aggregates), to have the same function as steel in reinforced concrete, or both. Macroscopically is the material strength characterized by the Young`s modulus $E$, Poisson`s ratio ν and namely by the fracture stress. Structural strength, on the other hand, is related to the interaction among the building units and depends on several variables, namely egg dimensions, egg shape, eggshell thickness, and distribution of the shell components. Most techniques that aim at quantifying eggshell strength measure eggs as a whole and thereby make no distinction between these two properties.

The most common technique for the measurement of the shell strength consists in the compression of the egg between two plane plates. This technique has been mostly applied for the study of the mechanical properties of the hen`s eggs **(De Ketelaere et al., 2002; Lin et al., 2004; Narushin et al., 2004, Altuntas and Sekeroglu, 2008, Nedomová et al., 2009)**. There are also some papers on the mechanical behaviour of Japanese quail eggs **(Polat et al., 2007)**, on the strength of the Ostrich`s eggs **(Cooper et al., 2009)** and many others. The data on the mechanical behaviour of goose`s eggs are very scarce in the literature.

The aim of this study was to determine the mechanical behaviour of the goose`s eggs under their compression between two plane plate. The main emphasis has been given on the effect of the compression velocity on the parameters describing the eggshell strength, i.e. on the rupture force, eggshell deformation at the rupture, on the energy absorbed during the loading process etc. The study of this effect is limited only to the hen`s eggs. It has been found that the eggshell strength has been significantly depended on the compression rate **(Voisey and Hunt 1969; Carter, 1979, Altuntaş and Şekeroğlu, 2008)**. The investigation of the loading rate on the strength properties of the goose`s eggs should extent our knowledge on this phenomenon.

MATERIAL AND METHODOLOGY

226 eggs (3 days old) from *Landes* geese were chosen for the experiment. Geese were kept in free-range technology at a commercial breeding farm in the Czech Republic. Eggs were collected from 3 years old geese.

In this paper the analytical description of the eggshell contour curve was also obtained. This description enables to evaluate the radius of the curvature R, egg volume and egg surface. The radii were evaluated at the sharp end, blunt end, and at the maximum width of the egg (equator).

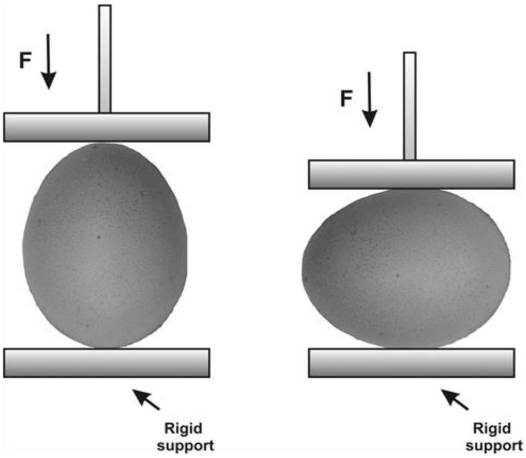

Figure 1 Schematic of the egg compression. On the left side the loading along the X-axis is shown. The loading along the Z-axis is displayed on the right part. This orientation is also termed as the loading in the equator plane

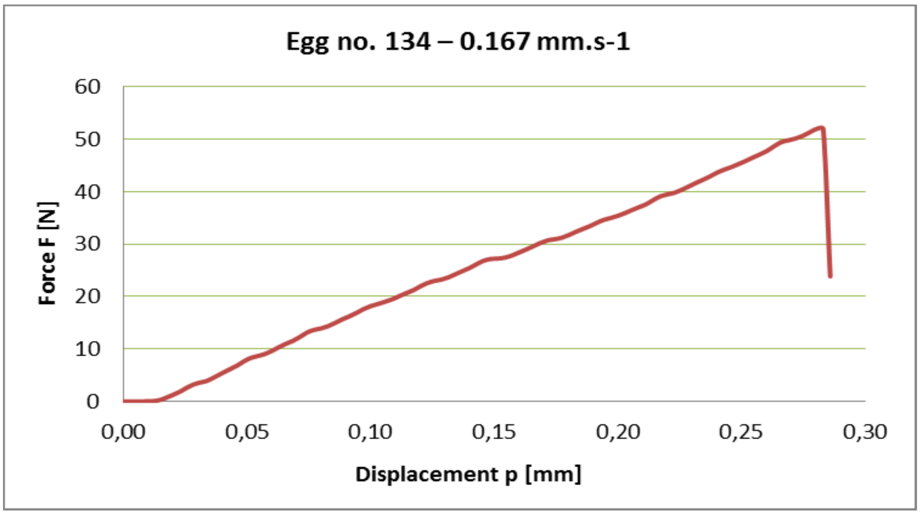

Figure 2 Example of the experimental record of the force during the compression of egg along the Z axis

Table 1 Thickness of the eggshells of the tested eggs

	Sharp End [mm]	**Blunt End [mm]**	**Equator [mm]**	**Average [mm]**
Minimum	0.248	0.267	0.321	0.313
Mean	0.505	0.460	0.511	0.492
Maximum	0.722	0.659	0.681	0.642
St. deviation	0.0838	0.0821	0.0681	0.0698

In order to complete the basic data the values of the eggshell thickness are given in the Table 1.

These quantities have been measured at the sharp end of the egg, at the blunt egg and at the maximum of the egg width (at the equator).

The eggs have been compressed between the two plates using testing device TIRATEST 27 025 (TIRA GmbH, DE). The egg sample was placed on the fixed plate and loaded at the compression velocities 0.0167, 0.167, 0.334, 1.67 and 5 mm.s^{-1} and pressed with a moving plate connected to the load cell until the egg ruptured. Two mutually perpendicular compression axes (*X*, *Z*) corresponding to main geometrical axes were used – see Figure 1.

The *X*-axis represented loading axis along the length dimension and the *Z*-axis represented the transverse axis covering the width dimension. Two more orientations were considered in case of *X*-axis. If the egg sharp end is in contact with the moving plate the symbol X_s is used. The symbol X_b corresponds to the orientation where egg blunt end is in contact with the moving plate.

Response of the egg to compression loading between two parallel plates is characterized by nearly linear increase in the loading force, *F*, with moving plate displacement *p*. At the moment of eggshell break the loading force rapidly decreases – see Figure 2.

This behaviour was observed in number of researches and described in many; see e.g. **De Ketealere et al. (2004)** and **Lin et al. (2004)**. Maximum of the loading force is than defined as the rupture force, F_m. Specific rupture deformation is defined by the following equation:

$$\varepsilon_f = \frac{p_m}{L}, \qquad (1)$$

Where *L* (mm) is the undeformed egg length measured in the direction of the compression axis and p_m (mm) is the displacement at the point of rupture of the eggshell **(Braga et al., 1999)**. Energy absorbed (E_a) by an egg at the moment of rupture is defined as:

$$E_a = \int_0^{D_r} F(x)dx. \qquad (2)$$

The series of 10 eggs was tested for each orientation.

RESULTS AND DISCUSSION

The experimental records force – displacement have been used to the evaluation of the quantities described in the previous charter. The results are summarized the Tables 2 – 4, where the basic statistics of the obtained data is presented.

The rupture force increases with the compression velocities as shown in the Figure 3.

For all used orientation of the egg compression the rupture force exhibits its maximum in such loading orientation, when the moving plate is in contact with the sharp end of the egg (X_s axis). The experimental data can be fitted by power function:

$$F_m = Ap^n. \qquad (3)$$

The parameters are given in the Table 5.

These results are generally similar to those obtained by **Altuntaş and Şekeroğlu (2008)** and **Trnka et al. (2012)**. Contrary to the results obtained for the hen`s eggs the goose`s eggs exhibit higher sensitivity of the rupture force to the loading rate. This rate sensitivity can be described by:

$$\frac{dF_m}{dv} = Anv^{n-1}. \qquad (4)$$

Owing to the values of n – see Table 4 – the increase in the loading rate v the rate sensitivity decreases. The same tendency as the rupture force exhibits also absorbed energy E_a – see Figure 4.

These data can be also fitted by the function (3). The parameters of this fitting are presented in the Table 6.

The displacement p_m at the egg rupture increases with the compression rate v. Its dependence on the orientation of the loading is not the same as for rupture parameters F_m and E_a – see Figure 5.

The egg shape can affect the obtained results. In **(ASAE, 2001)** method for compression tests of food materials of convex shape is described. According to this theory the loading force should be dependent on the main curvature of the eggshell. If we denote the radii of the curvature at the sharp end as R_1, at the blunt end as R_2 and at the equator as R_3 than for the loading in the X_s, X_b and Z-axes we obtain the curvatures k_1, k_2, k_3:

$$X_s \qquad k_1 = \frac{2}{R_1},$$

$$X_b \qquad k_2 = \frac{2}{R_2},$$

$$Z \qquad k_3 = \frac{1}{R_3} + \frac{1}{W},$$

Where W is the egg width.

In the Figure 6 the dependence of the rupture force on the eggshell curvature is displayed for the compression velocity 0.0167 mm.s^{-1}.

The rupture force F_m increases with the eggshell curvature *k*. Experimental data can be fitted by the power function:

$$F_m = ak^b + c. \qquad (5)$$

The same conclusions have been obtained for all remaining loading velocities. Parameters of the Eq.(5) are given in the Table 7.

The remaining eggshell strength characteristics also increase with the eggshell curvature. The obtained data can be fitted only by polynoms of order 6 and more.

The effects of the eggshell thickness on rupture parameters were not statistically significant. These characteristics are also independent on the egg shape index SI. This independence may be consequence of a relatively low scatter both of the thickness and SI.

As it has been mentioned in the introduction the rupture force obtained at the compression of the whole egg consists from the material and structural strength. In order to distinguish these two components some numerical simulation of the egg compression should be used. One of the possible approaches has been presented by **Trnka et al. (2012)**.

The explanation of the increase in the eggshell strength with the loading rate can be probably explained only in terms of the eggshell microstructure like in the case of many engineering materials (metals, ceramics, polymeric materials etc.).

Table 2 Compression in the X_s direction

	Compression velocity				
	0.0167 mm.s^{-1}	0.167 mm.s^{-1}	0.334 mm.s^{-1}	1.67 mm.s^{-1}	5 mm.s^{-1}
	F_m [N]				
Minimum	60.25	75.45	93.36	118.14	132.38
Mean	64.05	83.33	101.92	122.41	136.67
Maximum	67.36	88.21	106.48	127.75	150.55
Standard deviation	2.030	3.734	3.744	2.876	4.943
	p_m [mm]				
Minimum	0.23	0.24	0.40	0.40	0.51
Mean	0.25	0.30	0.43	0.48	0.55
Maximum	0.28	0.37	0.46	0.56	0.71
Standard deviation	0.014	0.046	0.020	0.057	0.056
	p_m/L [%]				
Minimum	0.260	0.271	0.453	0.426	0.539
Mean	0.286	0.338	0.488	0.530	0.610
Maximum	0.315	0.420	0.524	0.632	0.798
Standard deviation	0.018	0.050	0.022	0.064	0.079
	E_a [Nmm]				
Minimum	6.30	8.23	17.82	21.69	30.80
Mean	7.25	11.41	19.99	26.86	34.11
Maximum	8.05	14.44	22.26	32.52	48.59
Standard deviation	0.50	2.10	1.48	3.74	4.99

Table 3 Compression in the X_b direction

	Compression velocity				
	0.0167 mm.s^{-1}	0.167 mm.s^{-1}	0.334 mm.s^{-1}	1.67 mm.s^{-1}	5 mm.s^{-1}
	F_m [N]				
Minimum	39.40	51.32	70.56	81.65	107.25
Mean	43.21	53.70	72.82	84.81	111.43
Maximum	48.10	57.26	75.21	88.67	118.14
Standard deviation	2.97	.98	1.30	2.38	3.20
	p_m [mm]				
Minimum	0.22	0.20	0.28	0.29	0.30
Mean	0.28	0.30	0.32	0.32	0.33
Maximum	0.33	0.33	0.36	0.36	0.36
Standard deviation	0.03	0.03	0.02	0.02	0.02
	p_m/L [%]				
Minimum	0.238	0.210	0.308	0.330	0.191
Mean	0.309	0.331	0.358	0.356	0.361
Maximum	0.378	0.375	0.413	0.430	0.436
Standard deviation	0.041	0.043	0.029	0.029	0.076
	E_a [Nmm]				
Minimum	4.28	5.21	9.42	10.78	14.95
Mean	5.45	7.24	10.55	12.28	16.67
Maximum	6.43	8.19	11.55	14.51	19.33
Standard deviation	0.75	0.85	0.74	1.06	1.45

Table 4 Compression in the *Z* direction

	Compression velocity				
	0.0167 mm.s^{-1}	0.167 mm.s^{-1}	0.334 mm.s^{-1}	1.67 mm.s^{-1}	5 mm.s^{-1}
	F_m [N]				
Minimum	23.68	40.26	60.02	70.25	82.18
Mean	37.35	50.71	63.80	73.02	85.24
Maximum	45.71	59.55	67.03	77.11	88.32
Standard deviation	7.99	7.13	2.51	2.08	1.90
	p_m [mm]				
Minimum	0.16	0.20	0.20	0.44	0.51
Mean	0.22	0.36	0.30	0.49	0.54
Maximum	0.29	0.83	0.39	0.59	0.59
Standard deviation	0.05	0.19	0.06	0.05	0.03
	p_m/W [%]				
Minimum	0.284	0.335	0.355	0.546	0.829
Mean	0.375	0.604	0.520	0.817	0.919
Maximum	0.494	1.409	0.660	1.040	0.996
Standard deviation	0.075	0.324	0.093	0.137	0.055
	E_a [Nmm]				
Minimum	1.83	3.66	5.65	14.50	19.66
Mean	3.76	8.48	8.68	16.28	20.87
Maximum	5.49	21.03	10.86	19.13	22.61
Standard deviation	1.36	5.18	1.73	1.57	0.92

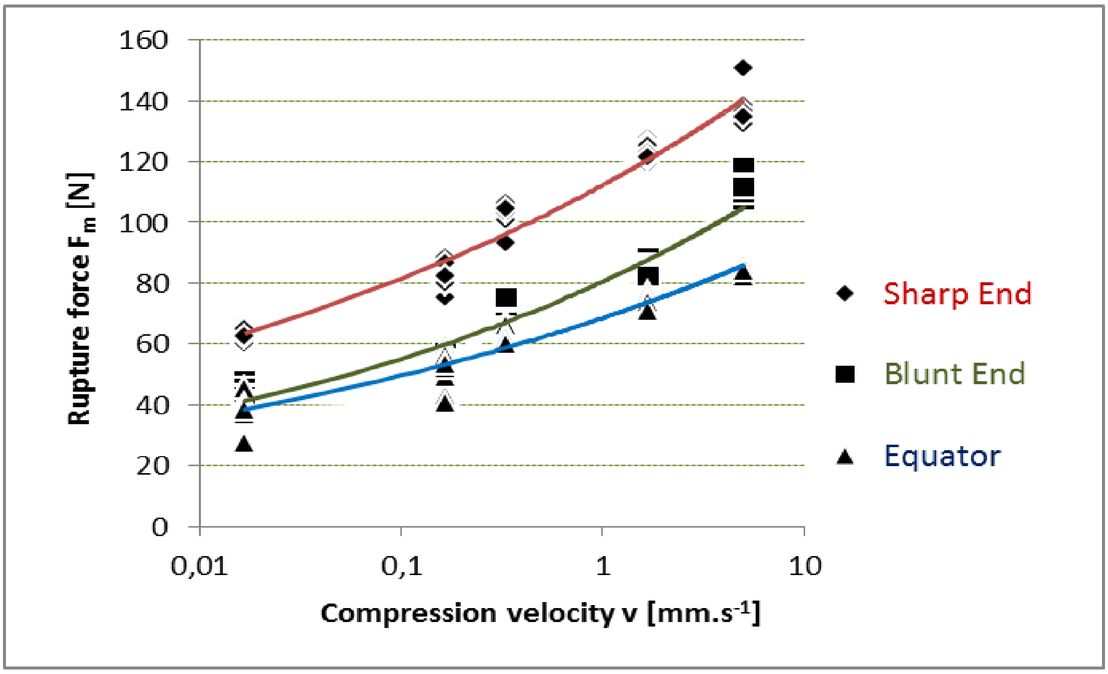

Figure 3 The influence of the compression velocity on the rupture force

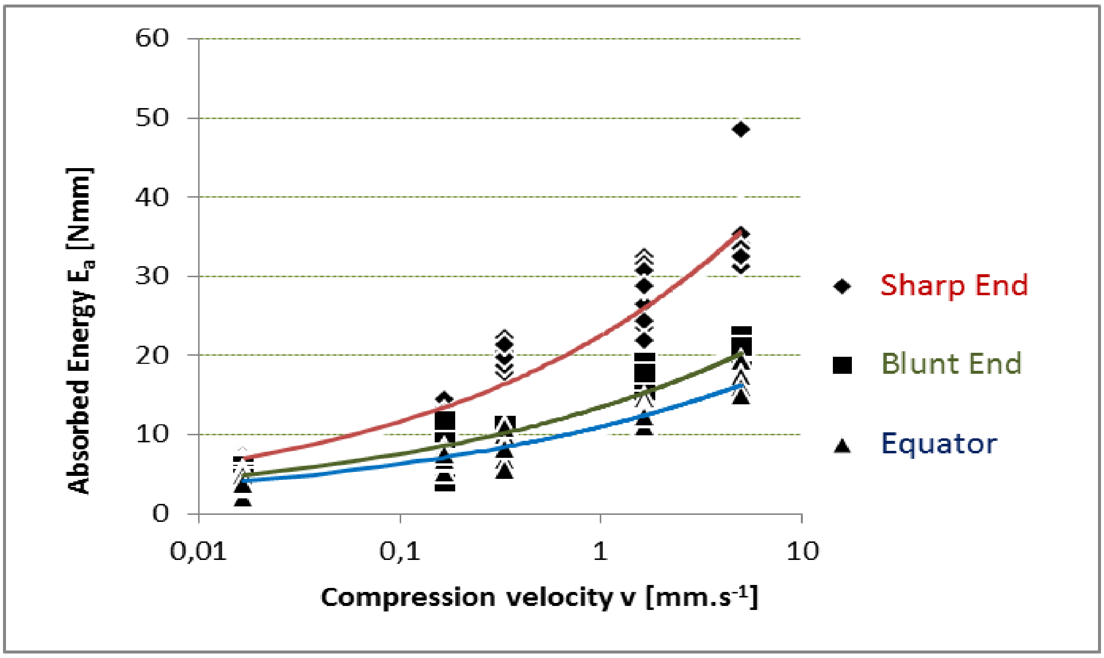

Figure 4 Energy absorbed up to the eggshell fracture

Table 5 Rupture force - parameters of Eq.(3). r^2 is the correlation coefficient

Compression orientation	A [n]	N [1]	R^2
	112.1	0.1341	0.9757
X_b axis	81.9	0.1754	0.9506
Z	68.6	0.1404	0.9408

Table 6 Absorbed energy - parameters of Eq.(3). r^2 is the correlation coefficient

Compression orientation	A [n]	N [1]	R^2
xis	22.80	0.2638	0.9631
X_b axis	11.78	0.2025	0.9611
Z	13.28	0.2919	0.9880

Table 7 Rupture force - parameters of Eq.(5). r^2 is the correlation coefficient

Compression velocity $[mm.s^{-1}]$	a $[Nmm^{-1}]$	b [1]	c [N]	r^2
0.0167	9726	2.899	35.94	0.6386
0.167	52210	3.695	49.42	0.6039
0.334	13010	2.778	70.87	0.8757
1.670	8881	2.638	61.99	0.8334
5.00	40030	3.33	80.59	0.7233

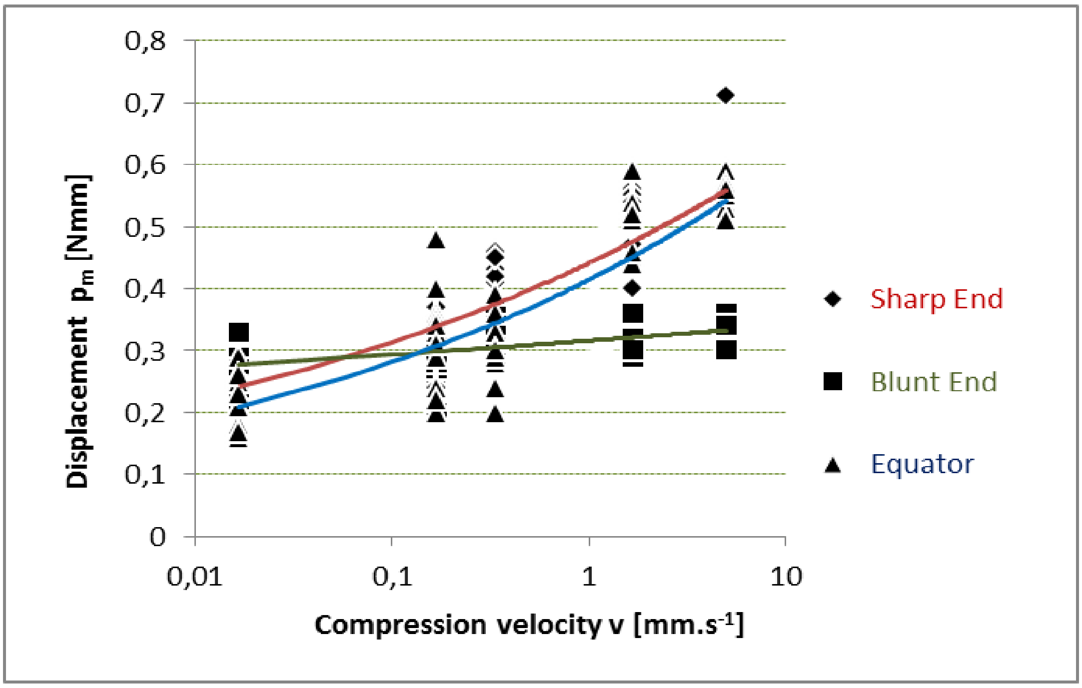

Figure 5 Eggshell displacements at the moment of the eggshell breakage

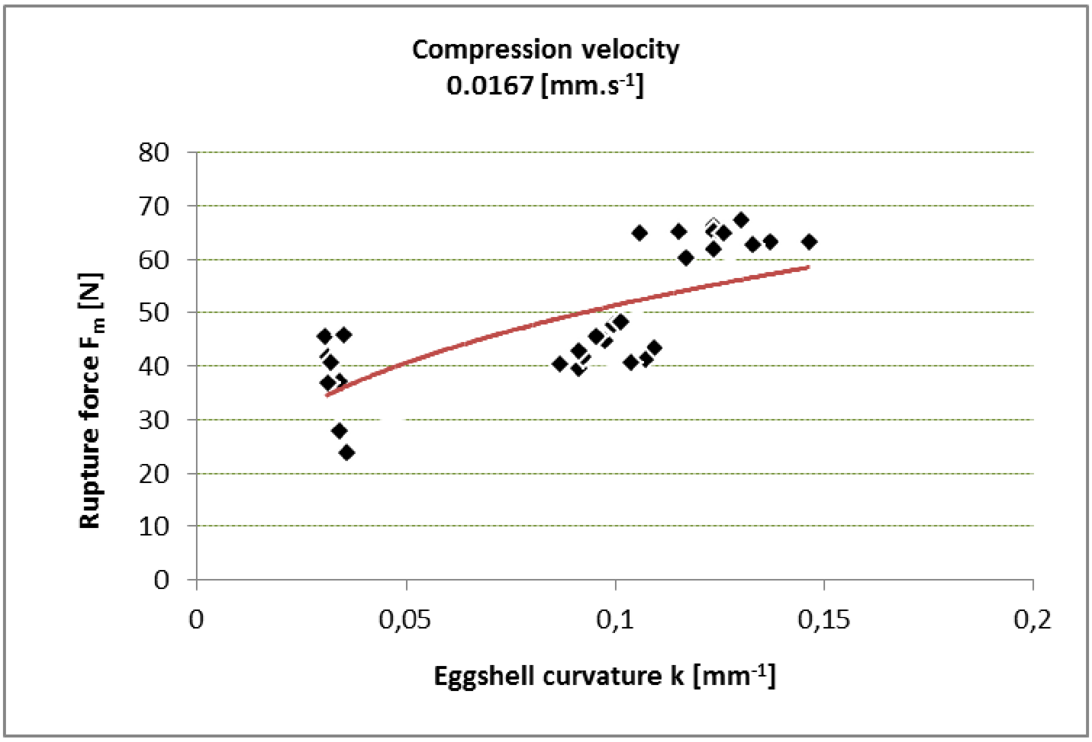

Figure 6 The influence of the eggshell curvature on the rupture force

CONCLUSION

The results obtained within presented research show on significant influence of the compression rate on the eggshell strength. The eggshell strength was described by the rupture force, specific rupture deformation and by the absorbed energy. The rupture force is highly dependent on compression speeds. The dependence of the rupture force on the compression velocity can be described by a power function. The same is valid for the rate dependence of the energy absorbed by the egg up to the fracture. Specific rupture deformation depends on the compression velocity by the same way as the rupture force. At the same time the dependence of this deformation on the loading orientation is different from that observed for the rupture force.

The highest rate dependence was observed for loading in the X_a direction, while the lowest in the Z direction.

The dependence of the rupture force on the orientation of compression axis can be quantitatively described as function of the main curvature of the eggshell surface, which is in the contact with the loading plate. This parameter is thus more important than the egg shape index SI which is widely used for the hen`s eggs description.

The increase of the rupture force with loading velocity is higher than that observed for the technical materials (metals, ceramics, polymeric materials etc.). The explanation of these phenomena represents a challenging problem for the next study.

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