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IDENTIFICATION OF THE EGGSHEL ELASTIC PROPERTIES

IDENTIFIKACE ELASTICKÝCH VLASTNOSTÍ VAJEČNÝCH SKOŘÁPEK.

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The problem of the identification of the elastic properties of eggshell, i.e. the evaluation of the Young`s modulus and Poisson`s ratio is solved. The eggshell is considered as a rotational shell. The experiments on the egg compression under quasistatic loading have been conducted. During these experiments a strain on the eggshell surface has been recorded. The numerical simulation of these experiments has been performed. By the mutual comparison between experimental and numerical values of strains the influence of the elastic constants has been demonstrated.

Keywords

Eggshell Young`s modulus Poisson`s ratio strength finite element strain gauges pressure test

INTRODUCTION.

The elastic properties belong to key engineering properties of egg shell material. Their knowledge enables e.g. the evaluation of the eggshell strength which is the important parameter of the egg quality (Lin J. et al 1993, Carnarius et al., 1996, Boushy and Ratering, 1993, Rezac et al,2000, Nirasawa et al. 1998, Picman and Pripil 1997). There are different experimental technique of the eggshell strength measurement see e.g. Bain (1997) for a review. One of them is the quasi – static compression test which corresponds to the loading of eggs during their packing. During this test, eggs are compressed between two parallel plates by a steadily increasing load until failure results. This procedure enables to determine the force and the shortening of the egg at the moment of failure. This force is affected by many factors as e.g. by the eggshell geometry (shape and thickness), by the velocity of loading and by many other factors which more or less cover the influence of the intrinsic material properties. The exact evaluation should lead to the values of stress and strain at the failure. These parameters may be easily obtained from test mentioned above if we use flat testing

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specimens. The eggs exhibit a more complicated shape but they may be considered as a shell of revolution. The evaluation of the eggshell strength thus must involve the following steps :

- experiment described above
- the choose of the eggshell material model
- the evaluation of the stress and strain in the eggshell at the moment of the eggshell failure

The eggshell is mostly considered as isotropic elastic material. The elastic properties of this material are described e.g. by the Young modulus E and by the Poisson`s ratio ν and / or by the Young modulus and by the shear modulus G, respectively. The stress and strain mentioned above can be determined only by the indirect way. There are some papers dealing with this problem which are summarized in review (Bain, 1997).

In order to avoid the complications connected with the egg`s shape some authors used a ring cut from the eggshell near of the egg equator (Rehkugler 1963, Lin et al 1995) . Some authors considered the egg as a sphere (Tung et al 1969). These simplifications enable the use of some analytical methods. If we consider the real shape of the eggshell some numerical methods must be used. The most common numerical procedure is the finite element method which is implemented in the most computer software like ANSYS, MARC etc. The finite element method has been used in some papers (Manceau and Henderson 1970, Bain 1990, Eantwistle. et al. 1995).

In the given paper we have focused on the solution of the problem of the eggshell strength evaluation using the numerical procedure mentioned above.

EXPERIMENTAL PROCEDURE AND RESULTS.

For the experiments hen`s eggs have been used. The shape of the egg has been determined from the digital photo of the egg by the procedure described by Barton and Krivanek (2001) . The eggshape can be described by the parametric equations :

$$x = a\cos(\varphi), y = a\sin(\varphi)$$

where

$$a = k_1 \frac{1 + k_2\cos(\varphi)}{\sqrt{k_3\cos^2(\varphi) + \sin^2(\varphi)}}$$

The used values of constants are : k_1 = 21.079 mm, k_2 = 0.172, k_3 = 0.505.

These eggs has been compressed using of the testing machine TIRATEST at the velocity 20 mm per minute. On the surface of the egg a strain gauge has been glued see Fig.1.

The egg has been loaded by the following way :

- Loading up to 10 N and subsequent unloading
- The previous step is repeated for the forces 15, 20 , 25, 30 N
- At every value of the force a relaxation test has been performed , the deformation corresponding to this force has been kept constant for 240 seconds and the force vs time has been recorded.
- The egg has been loaded up to failure

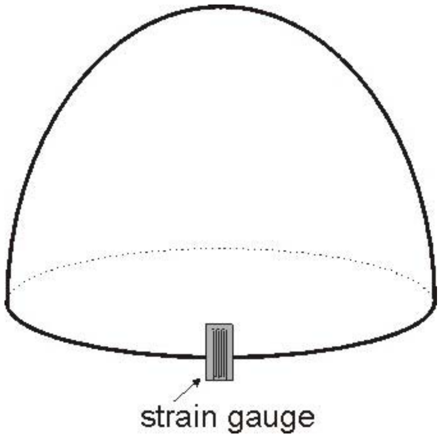

Fig.1.Schematic of the eggshell loading in compression using of the TIRATEST texsting machine.. The length of the strain gauge is 2 mm. The strain has been recorded via the "Spider" recorder

From the relaxation experiments the assumption on the elastic behaviour of eggs has been approved.

In Fig.2 the record of time dependence of the force at the top of egg is displayed. The fig.3 shows the record of the force in the case of the egg failure. The force at the failure is about 49 N. The failure has a form of a thin crack which propagates nearly in the meridian direction . The record of the strain is displayed in Fig.4. The record in Fig.2 corresponds to the loading to about 12 N. The egg deforms only elastically. The time record of strain in the case of the egg failure is shown in Fig. 5. One may see the release of the strain energy during the failure. In table 1 the values of maximum strains at the maximum load force F are given. At the same time the values of the egg shortening are also reported. The strain is increasing function of the maximum loading force as shown in Fig.6. The dependence is linear.

Table 1. Experimental values of the loading force, strain and egg shortening.

FORCE F (N)	12.03	15.26	20.61	25.83	30.91	49.54
STRAIN (x 0.001)	4.32	4.68	5.76	6.96	7.68	9.60
SHORTENING (mm)	0.100	0.127	0.133	0.187	0.222	0.347

The shortening of the egg depends on the loading force linearly as it is documented in Fig.7. The linearity of this dependence should be verified for another points on the surface of the egg.

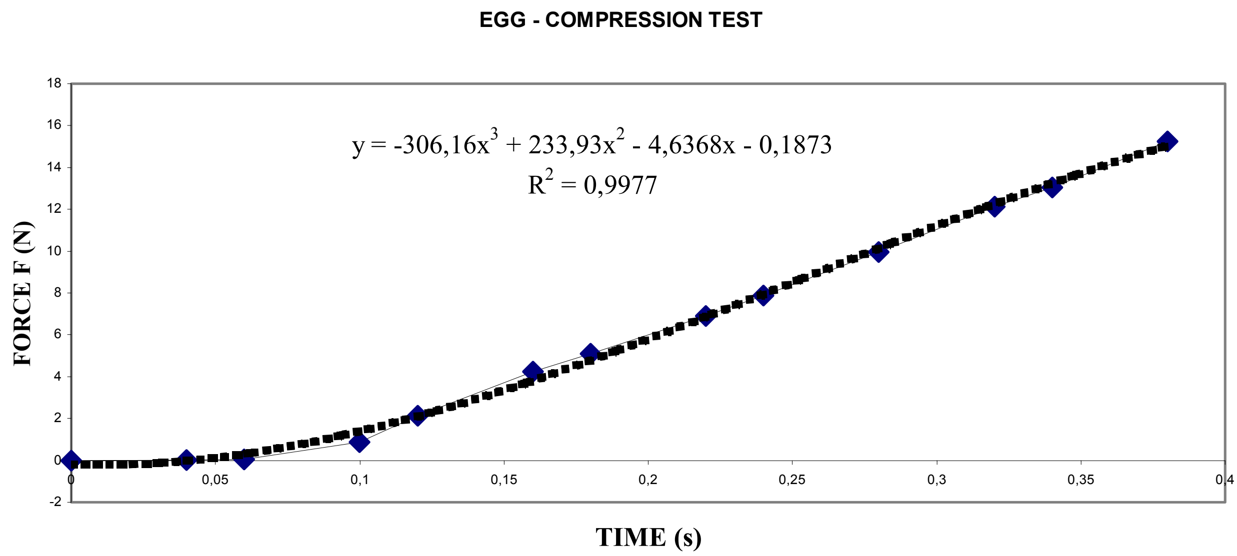

Fig.2. The experimental record loading force on the time. No damage of the egg occurred .

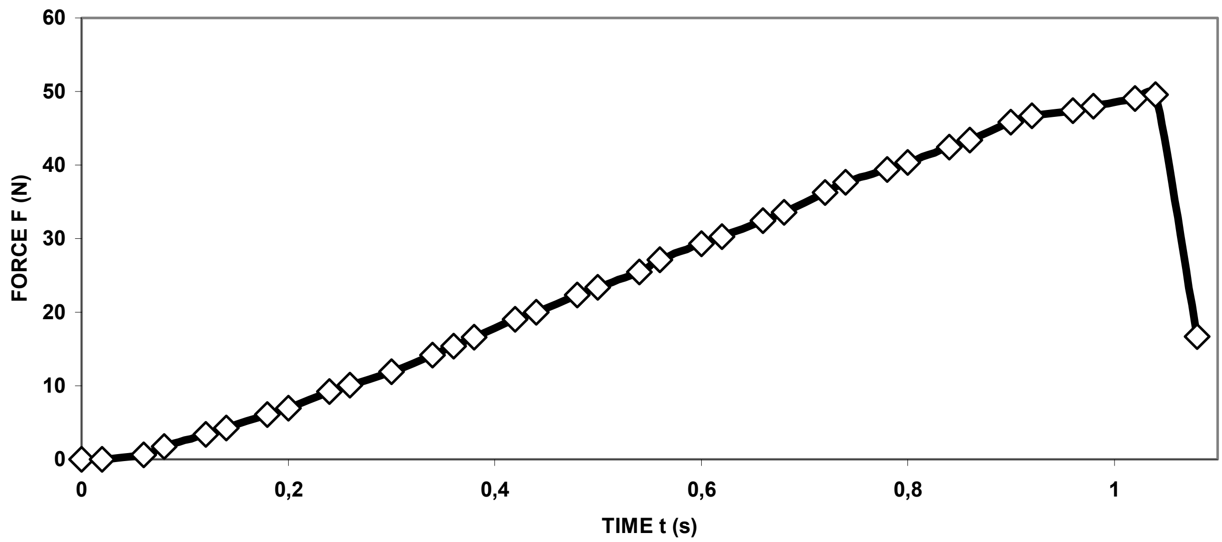

Fig.3. The experimental record loading force on the time. At the maximum of the force failure of the egg starts. The failure is in the form of the single crack. The crack propagates nearly along the meridian.

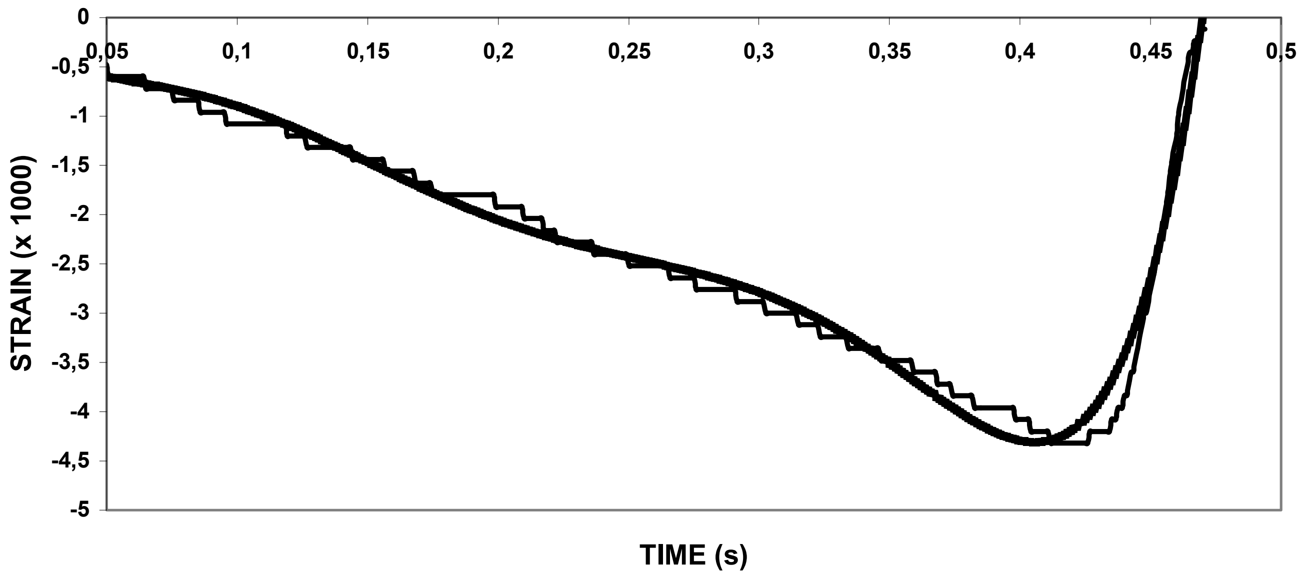

Fig.4.The experimental record of the strain. (The smooth curve corresponds to polynominal fit of the experimental data)

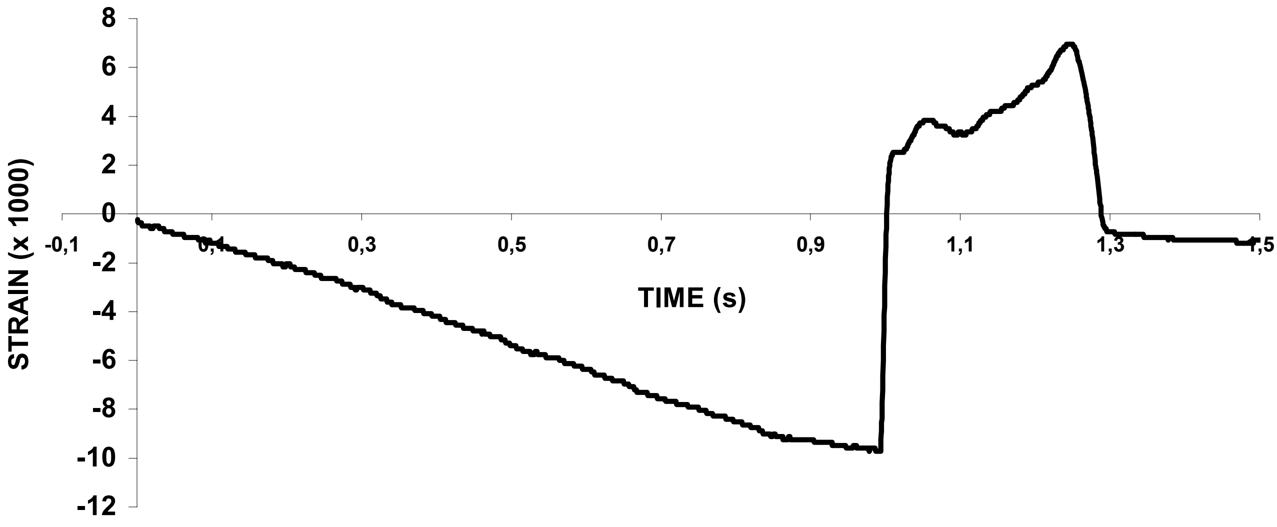

Fig.5. The experimental record of the strain. The egg has been failed.

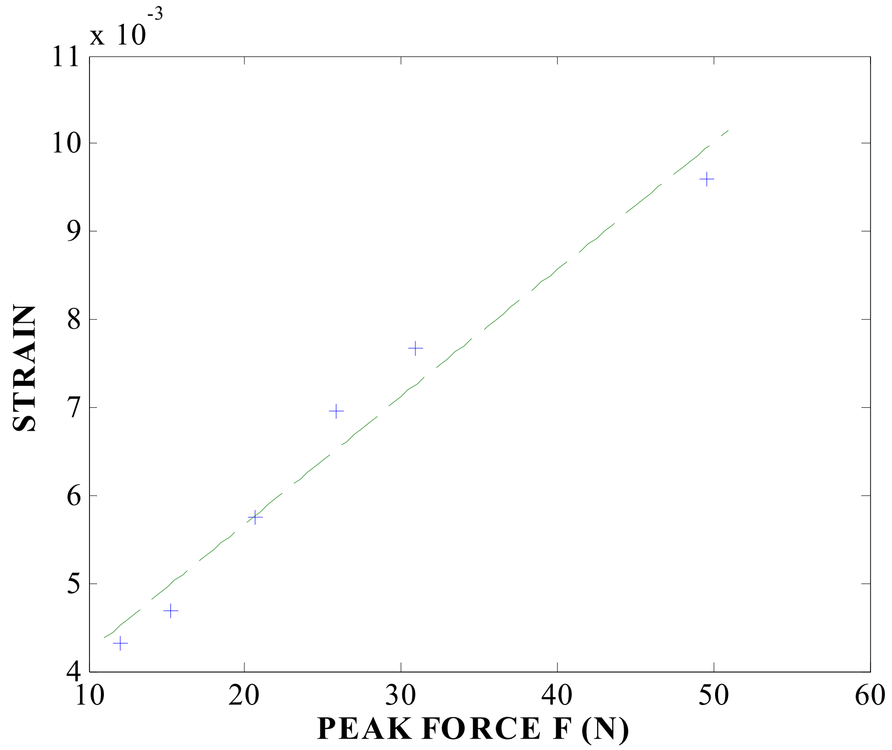

Fig.6 The dependence of the strain on the loading force.

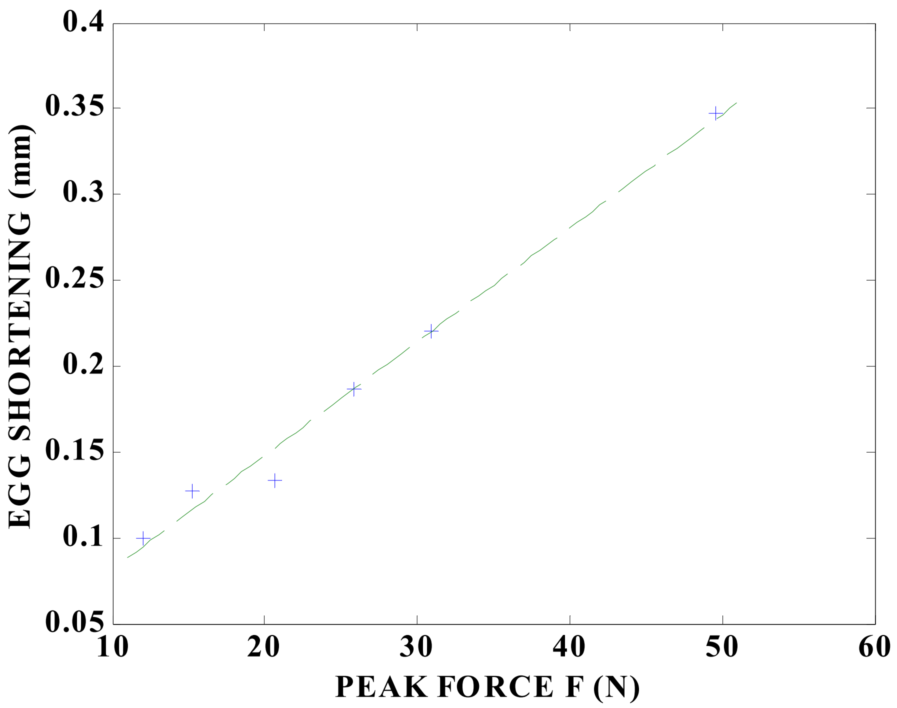

Fig.7.The change of the egg size as function of the loading force.

NUMERICAL SIMULATION.

In the next step we have used the model of the shell loading described in the previous chapter.

The eggshell has been taken as homogeneous and isotropic . The thickness of the eggshell is 0.35 mm. The elastic properties of the shell are described by the Young`s modulus E and by the Poisson`s ratio ν. The values of these parameters are given e.g. in review paper (Bain,1997) . According to the different sources the values of E and ν vary in a broad interval. For the sake of a simplicity the yolk and the white of egg have been considered as a mixture with the density which is given by the densities of the both components. The viscosity of this mixture has been tested e.g. in (Dawson, 1996) . It has been found that this liquid behaves as non Newton`s liquid where the apparent viscosity coefficient μ linearly decreases with the strain rate γ. At the temperature T = 20°C this dependences has a form .

$$\mu = 10^{-3}(9.6 - 0.0024\gamma) \qquad\qquad in \quad Pas$$

It is obvious that this approach represents a rather simplified solution which will be improved in our forthcoming papers. The compressibility of the mixture of the yolk and the white of egg has been taken the same as for the water . The air has been considered as an ideal gas and the constitutive equation of this gas has been used.

The ANSYS finite element code has been used. We have performed a serie of computations of the strain values for the given values of the loading force and for the different values of E and ν. Results are given in Table 2. It has been shown that the numerical results are only slightly depended on the egg`s liquid viscosity (Buchar and Simeonova 2001).

Table 2. Computed values of strains.

FORCE (N)	E (Mpa)	ν (1)	STRAIN (x 0.001)
F = 12.03 N	15 000	0.30	4.28
		0.35	4.62
		0.40	4.82
	25 000	0.30	3.96
		0.35	4.15
		0.40	4.26
	35 000	0.30	3.27
		0.35	3.56
		0.40	3.98
	15 000	0.30	4.35
		0.35	4.75
		0.40	4.97

F = 15.26 N	25 000	0.30	4.18
		0.35	4.42
		0.40	4.75
	35 000	0.30	4.03
		0.35	4.27
		0.40	4.51
F = 20.61 N	15 000	0.30	4.82
		0.35	5.11
		0.40	5.43
	25 000	0.30	4.61
		0.35	4.93
		0.40	5.20
	35 000	0.30	4.43
		0.35	4.78
		0.40	5.07

In Figs. 8 – 10 the dependence of the strain on the Young modulus and Poisson ratio are plotted..

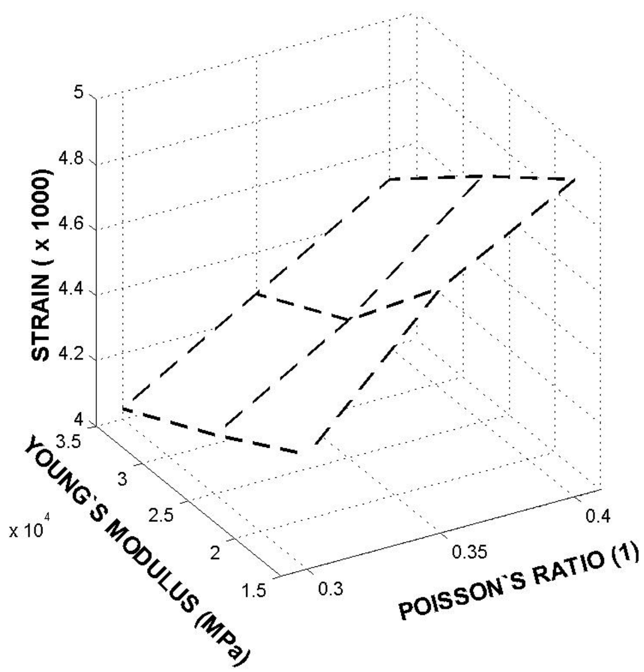

Fig.8 The dependence of the computed strain on the elastic parameters. Loading force F = 12.03 N.

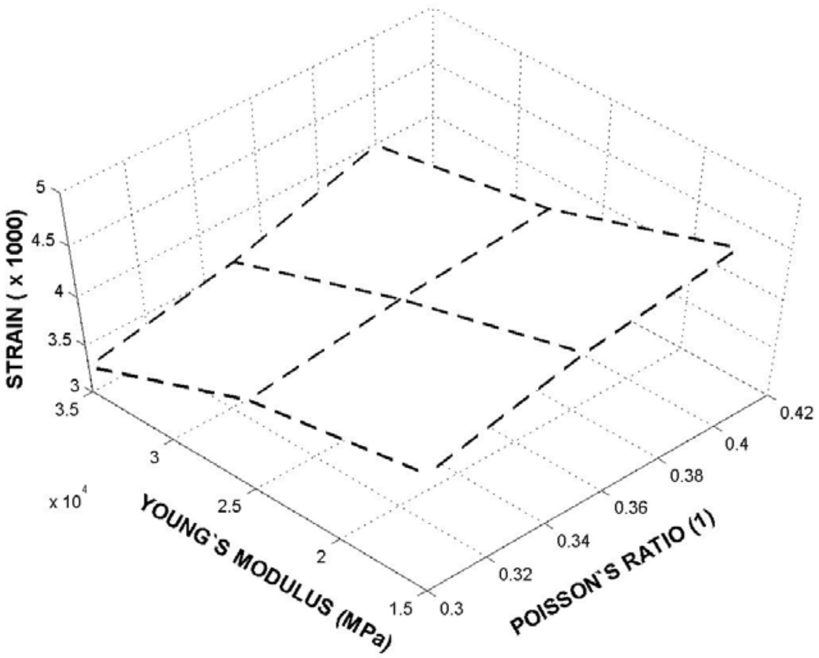

Fig.9. The dependence of the computed strain on the elastic parameters. Loading force F = 15.26 N.

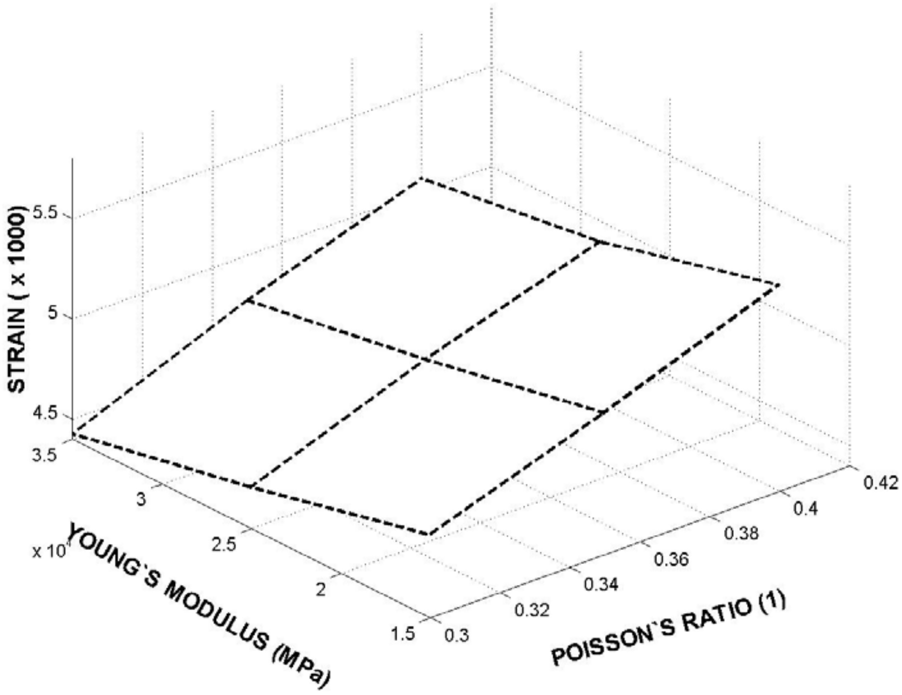

Fig.9. The dependence of the computed strain on the elastic parameters. Loading force F = 20.61N.

This procedure has been repeated for another values of the loading force. It has been shown, that the best agreement between experimental data and theory has been achieved for the following values of the elastic constants :

$$E = 23\ 000 \text{ MPa}, \nu = 0.34$$

If we use the value of the force at which the eggshell failure occurs the numerical computation gives the value of the tensile stress near of the point of contact 19.3 MPa. This stress can be considered as the eggshell strength.

In the next step the obtained elastic constants has been used for the simulation of the egg behaviour falling from the height 6 cm on a rigid plate – see Fig. 10. This behaviour has been studied experimentally as well as numerically. Numerical simulation of this event has been performed using of the LS DYNA 3D finite element code (Simeonovova and Buchar, 2001). During theexperiments the steel plate has been used. Owing to the material properties of the steel the plate can be considered as a rigid anvil. The experiments suggest that the egg damage is nearly the same as the eggshell failure at static loading by the procedure outlined in Fig.1. In Fig.11 the computed resultant force between eggshell and rigid plate is shown. It may be seen that the peak of this force exceeds the critical value of the force at which the eggshell failure starts. The value of the tensile stress near of the point of eggshell impact on the plate has been found to be 18.7 MPa. This stress is very closed to that obtained at the static loading. It seems that the eggshell strength may taken as at least 18 MPa. This value lies in the range of strength values reported in the published papers.

CONCLUSIONS.

In the given paper we have focused on the identification of the elastic properties of the eggshell. The proposed procedure uses both experiments and numerical simulation. Numerical simulation has been performed using finite element codes : ANSYS (static loading) and LS DYNA 3D (dynamic loading). The eggshell strength value has been obtained from the experiments at quasi – static compression . Its validity has been verified for the impact loading of the eggshell .

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