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Investigating Structural Strength of Egg as Shell Structure

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ABSTRACT

Considering the God's wisdom can improve human scientific growth and his awareness about the world considerably. It can accelerate human knowledge. Reviewing "why no one has been able to break an egg between his hands so far?" is basis of the present research. There is made two soft and flexible fulcrum for both ends of egg by inspiring human palms. Then it is tested compressive strength of egg types with different geometrical shapes as uncooked, cooked and without contents in a testing machine. The maximum achieved failure load is 750 N. The initial results of the experiment show that egg contents are not involved in resistance. Then the egg is modeled in Ansys software, and there is conducted linear and nonlinear static analysis of materials and geometry. Results show that its geometry shape does not play a major role in bearing capacity, and orbital tensile tensions are failure factors. In equal thicknesses, eggs with ratio of length to width 1.5 and 1.7 roughly have the highest and lowest bearing capacity respectively.

KEYWORDS: egg, geometrical characteristics, axial pressure strength, linear static analysis, nonlinear static analysis, geometry and materials

1.INTRODUCTION

wisdom indicates that the world has been created based on exact order and regularity as well as well-balanced and comprehensive regulations in all forms. The God's works have wisdom on all aspects. This is called the best order. Considering the God's wisdom can affect human scientific growth and his awareness about the world considerably. It can accelerate human knowledge. If we know that a skillful architect with wisdom in every place has made such a magnificent and great construction, we will not ignore its creatures and events and we will examine each phenomenon as a noteworthy matter.

The God's wisdom means that His works follow a defined purpose. Any of His works are not vain and useless. The following verses refer to meaning of wisdom.

Verse "It is God who created, coordinated, measured and guided [1].

Verse "We have not created heavens and the earth and what is between them in vain" [2].

Egg high pressure strength is one of the world of beings because, despite its thin and calcareous shell, anyone has not been able to crack it between his hands while he places it as lengthwise. Therefore, we examine the strength and its reasons in this study.

1. Basic Concepts in Shells

Shells are one of the most abundant and diverse forms of constructions that can be found in physical world around us. Shell structures are considered as the highest types of structures from engineering point of view. Many types of natural structures have shell forms such as skull, seeds and many animal organs' protectors. Gas and water tanks, silos, arched dams and body of aircrafts, ships and vehicles are some examples of various applications of shell structures. Geometrically, shells are divided into two types: extendable and non-extendable. Extendable shells are those shells that their surface geometry can be changed to a covered page without cutting them; but non-extendable ones are not as the same. According to this definition, cylindrical and spherical shells are placed in the first and second groups respectively. From bearing and mechanical capability point of view, non-extendable shells have high strength because they resist against any imposed load to extend and change them. By considering type of creating geometry surface, eggshell is rotation one. The surface is obtained by rotating a curve around anaxis of symmetry.

2. Egg Recognition

Egg is a compound material containing shell, outer and inner membranes, air cell, albumen and yolk.

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Shell: it is calcareous with rough and grainy texture. Shell is covered by 7,000-17,000 microscopic holes. It is a semi-permeable membrane.

Inner and outer membranes: they are located between shell and albumen. These two transparent protein membranes provide a defensive barrier against bacterial invasion. The membranes are primarily made from keratin.

Air cell: it is a hollow chamber between albumen and shell that is located at wider end of egg.

Albumen: it includes 67% of weight of liquids in egg. Albumen contains 50% of total protein in egg.
Yolk: it allocates 33% of egg weight (rather than shell). Yolk consists 50% of protein in egg. Yolk is responsible to provide the required food supplies to grow [3].

3. Experiment Tools
3.1 A system to determine three-axis compressive strength for determining compressive strength. (Vali-e-Asr University, Rafsanjan)
It is a full digital system and can configure speed of loading. According to manufacturer's recommendations, its speed of loading was adjusted as equal to one percent of sample size. While it is 0.33-0.99 mm/s in the conducted research by AbouBakr and colleagues [4]. In the research, speed of loading is not consistent with the obtained speed of loading in the conducted researches by Ahmed and colleagues [5], Butcher and colleagues [6], Deklter and colleagues [7] and Vaisi and colleagues [8]. Figure 1-3 shows the system shape with the placed sample egg in it.

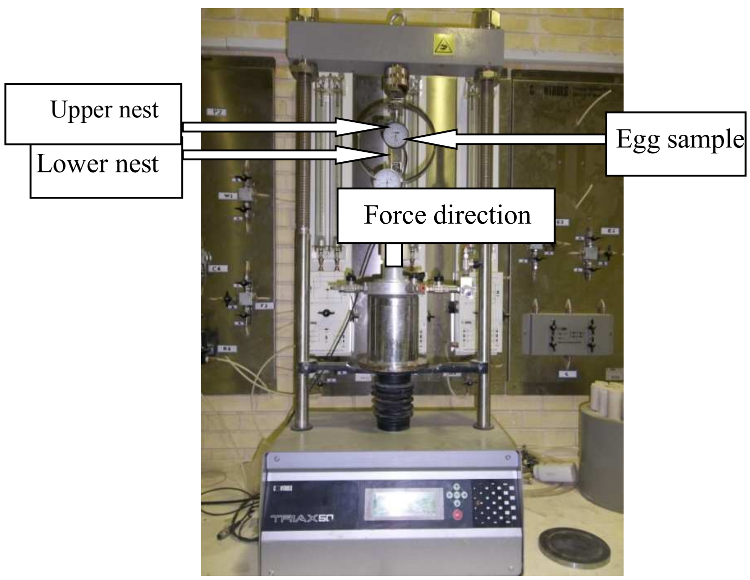


Figure 1.3: A system to determine three-axis compressive strength

3.2 Preparing sharp and wide bottom for egg
This was done in foundry workshop, and there was prepared central axis pattern of an egg sample as a plate with 5 mm thickness. Then there was possible to create nest deep on industrial Teflon cylinder by making two vertical cuts at beginning and end of metal plate.

3.3 Creating nest for a system to determine three-axis compressive strength (Vali-e-Asr University, Rafsanjan)
Based on the prepared model in the previous step, nest deep was created on Teflon cylinder. This was done in turning workshop with high precision. Then it was installed to test system ring. Figure 3-2 show upper and lower nests.

Fig. 3.2: nest of testing system

3.4 Preparing egg sample

3.4.1 Empty eggs: there were pierced some eggs with a syringe and their contents (albumen and yolk) was suctioned with diligence. Then the pore was blocked with a strong adhesive.

There was prepared a calcareous crustal structure containing no material. The interesting point is that it is necessary to pump air into egg by a syringe to extract its contents. If there was pumped air more than the considered volume, its shell would be cracked loudly. It indicates that shell strength is low against internal compression.

3.4.2. Cooked eggs: there was selected some cooked eggs. They were cooked for about 30 minutes in boiling water and they were safe after cooking.

3.4.3.Uncooked eggs: there were prepared 20 uncooked eggs.

METHODOLOGY

In their study, Cook, colleagues [9], Perian, and colleagues [10] used non-destructive method. McLeod et al [11], Ashley Lloyd, and colleagues [12] placed sample between two metal flat plates in their research. In the present research, all samples were placed inside a soft, flexible and deep nest as form of two heads of an egg. In the position, extensive load is imposed on egg sharp side, and its fulcrum is on bradawl of egg. Loading rate was adjusted as 1% of the samples length.

4.1 Test to determine role of egg contents on bearing capacity

There were used many samples to do the test. Many cases have very little bearing because of gliding fulcrum, invisible cracks or weaknesses in shell, changing shell thickness and strength due to different reasons including nutrition, disease and fear among birds. Therefore, they were not considered in calculations. After testing cases with same length, width and thickness as well as after statistical calculations (shell thickness is calculated after cracking), there were obtained results of strengthening final load until crack time for nine cases as Table 1.4.

TABLE 1.4: bearing capacity of eggs (mpa)

Egg type	Sample 1	Sample 2	Sample 3	Mean
Empty	539.5	397.0	501.0	479.2
Uncooked	531.0	606.0	333.0	490.0
Cooked	750.0	396.0	366.0	504.0

The above results indicate that egg bearing capacity is not depended on its inside contents (either watery liquid or semi-solid cooked). It depends on shell geometric shape and membranes attached to it. Therefore, egg is considered as an element entirely, and uncooked egg is used in next steps.

4.2 Experiment to investigate geometry and bearing capacity

For this purpose, there were selected nine different samples of eggs with the specifications given in Table 4-2. Rows 3 and 6 have maximum bearing capacity, which ratio of length to width is equal to 1.5. Rows 8 and 9 have minimum bearing capacity, which mean of ratio of length to width is equal to 1.7 with approximately equal thickness. The test results show that the eggs with oval, natural and spherical shapes have more resistant (approving the carried out research by Jacob and colleagues [15]). In other words, tall eggs have less resistance. This confirms the carried out research by Abu Altntas et al (in the carried out research by Abu Altntas et al, shape indicator (SI) is ratio of width to length). Meanwhile, maximum resistance occurs roughly in more thickness (the carried out research by Anderson et al [16]). Table 3.4 shows the remained geometric properties of cases.

Table 2.4: specifications of egg types

Row	Egg type	Local/machine	Egg color	Length (mm)	Width (mm)	Thickness (mm)	Weight (g)	Capacity (N)	Width/length
1	Empty	Machine	White	53.5	35	0.35	54	539.5	1.53
2	Uncooked	Machine	White	59.5	38	0.37	58	531	1.57
3	Uncooked	Local	White	53	35	0.35	56	606	1.51
4	Empty	Machine	White	59	36	0.36	58	397	1.64
5	Empty	Machine	White	53	34	0.35	58	501	1.56
6	Cooked	Machine	White	53	35	0.36	59	750	1.51
7	Cooked	Local	White	59	34.5	0.35	56	396	1.71
8	Uncooked	Local	White	60	35	0.36	56	333	1.71
9	Cooked	Local	White	61	36	0.36	56	366	1.69

Table 3.4: specifications of egg types

Row	Egg type	Ring coefficient	Egg total length (mm)	Egg free length (mm)	Egg maximum width (mm)	Shell thickness (mm)	Diameter of nest end (mm)
1	Cooked	0.82	53.50	31.50	35.00	0.35	21.00
2	Cooked	0.82	59.50	37.50	38.00	0.37	23.00
3	Cooked	0.82	53.00	31.00	35.00	0.35	25.00
4	Empty	0.82	59.00	37.00	36.00	0.36	22.00
5	Uncooked	0.82	53.00	31.00	34.00	0.35	24.00
6	Uncooked	0.82	53.00	31.00	35.00	0.36	22.00
7	Uncooked	0.82	59.00	37.00	34.50	0.35	23.00
8	Uncooked	0.82	60.00	38.00	35.00	0.35	22.00
9	Uncooked	0.82	61.00	39.00	36.00	0.35	23.50

Results of testing all samples were provided by Excel software and designing chart. The sample in row 6 of the above table is as Table 4.4 and its tension-strain chart is as same as Fig. 1.4. Using foam on fulcrum and its compression is reason of representing larger shift. As objective of the experiment is to determine egg-bearing capacity, we have to place foam under sample to prevent any crack. Tension-strain chart of all samples has a relatively same pattern. There was used lower area of the ring to calculate surface tension. In this method, maximum applied load on a small surface egg tip based on fulcrum is 750N. While maximum applied loads in the conducted researches by MacLeod, Ashley Lloyd et al, Deklir et al, Zatika Witt Royk et al [13], Plat and colleagues [14] and Tong and colleagues [17] are 40N, 200N, 37.8N, 35.3N, 10.5N and 31N respectively, regardless of loading method.

ε strain	σ strain	Power (N)	Gage	Length change (mm)	Strain
0.01	0.61	14.67	18.00	0.27	0.50
0.01	0.88	21.19	26.00	0.53	1.00
0.02	1.31	31.79	39.00	0.80	1.50
0.02	1.52	36.68	45.00	1.06	2.00
0.03	1.75	42.38	52.00	1.33	2.50
0.03	2.02	48.90	60.00	1.59	3.00
0.04	2.87	69.28	85.00	2.12	4.00
0.05	4.04	97.80	120.00	2.65	5.00
0.06	5.80	140.18	172.00	3.18	6.00
0.07	8.70	210.27	258.00	3.71	7.00
0.08	13.82	334.15	410.00	4.27	8.00
0.09	28.92	699.27	858.00	4.77	9.00
0.09	31.01	749.80	920.00	4.93	9.30
0.10	0.00	750.62	921.00	5.04	9.50

Table 4.4: results of case 6

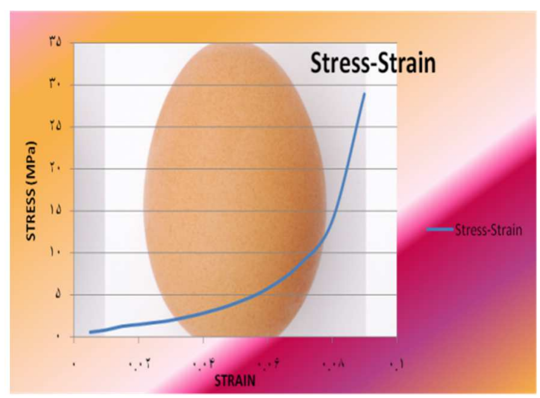


Fig. 1.4: tension-strain chart in case 6

Modeling egg in AutoCAD and Ansys software

To create a model in Ansys 13.0, we scanned an egg with more appropriate and natural shape. In next step, we recall it in AutoCAD and take necessary actions to produce real sample. Then they were stored suffix *.Sat and can be recalled in Ansys. X and Y indicate egg longitudinal axis and transverse axis respectively. Like Y-axis, Z-axis is widthwise too. There are considered two surfaces as loading and fulcrum levels in both sides of egg with depth of 11 mm based on empirical pattern and nest depth. Element Shell-181 was used for modeling. This 4-gram element is suitable for linear analysis as well as non-linear analysis of large rotations and strains, with its six degrees of freedom (3 transitional and 3 rotational).

5.1 Egg Elasticity Module

In their researches, Cook and colleagues, Tang et al. [18]–by using Reissner method-, Mac Lloyd and Bain [19] calculated 31,000 MPa, 46,000 MPa, 55,000 MPa and 30,000 MPa for egg elasticity module. In the present research, there ia considered 47,000 MPa for elasticity module of egg elements.

Types of the carried out analysis on eggs in Ansys program

Table 1.6 shows cases' specifications include length, width, shell thickness, length to width ratio, extend load volume (MPa) and loading surface (mm^2). As nest depth is 11 mm in the laboratory, there was considered loading surface as 11 mm from two ends of the sample in Ansys program.

Table 1.6: model specifications

Sample No.	Length (mm)	Width (mm)	Thickness (mm)	Width/length	Extended load (N/mm^2)	Loading surface (mm^2)
1	63.60	42.10	0.36	1.51	-0.85	887.20
2	72.00	42.10	0.36	1.71	-0.72	1047.20

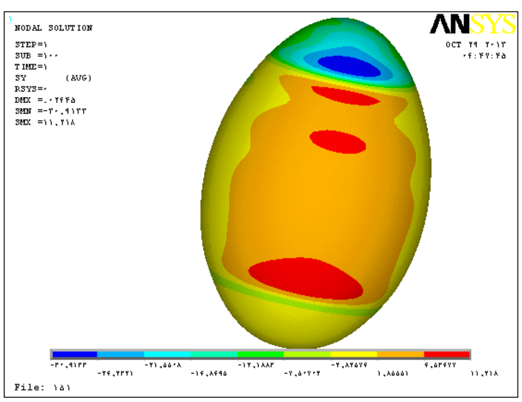
6.1 LINEAR STATIC ANALYSIS

There is considered 100 loaded steps, after making three-dimensional model in Ansys software with elastic modulus of 47,000 MPa and Poisson's ratio 0.25. load volume is 750 N based on maximum load. All steps are loaded in the analysis. Mm and MPa are units of displacement and tension respectively. S_x tensions represent the meridional tensions that are represented in egg transverse lengthwise direction; S_y tensions represent the circuit tensions that are represented in egg lengthwise direction. Negative and positive numbers indicate compressive and tensile tension respectively. S_{von} indicates Von Maisez tension. Table 2.6 and Figure 6.1 represent results of static analysis (MPa) and Sy tension in both samples respectively.

Table 2.6: output results of Ansys program-static analysis

Sample No.	Analysis type	Displace	Sx (min)	Sx (max)	Sy (min)	Sy (max)	S (von)	Passed step
1	Linear static	0.026	-22.5	0.39	-30.900	11.2	30.78	100/100
2	Linear static	0.034	-20	0.00	-36.800	9.32	35.3	100/100

Results of the above table show that all compressive tensions are meridional (S_x), but circuit tensions (S_y) are compressive in some points and it is tensile tension near fulcrum. These tensile tensions cause cracking and its direction along egg results to break sample from both sides.



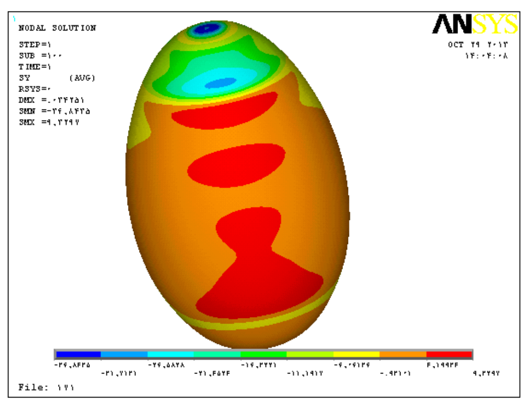


Figure 1.6.S_y tension in case 1 **Figure 2.6.**S_y tension in case 2

6.2 Nonlinear static analysis of geometry and material

For nonlinear static analysis of materials and geometry, there are entered material linear properties including elastic modulus equal to 47000 MPa, Poisson's coefficient equal to 0.25 and non-linear characteristics of materials including yield tension equal 30 MPa and tangent modulus equal 1 MPa based on available models and equation 1.6. We divide maximum resisted load from experimental results on sample cross-section on bottom of nest (circle × thickness) to calculate yield tension.

$$\sigma = \frac{P}{\pi . D\, t}$$

$$\sigma = 750/(3.14 * 22 * 0.36) = 30.15 \text{ MPa} \qquad (1.6)$$

To calculate the tangent modulus, egg tangent modulus is considered 1 because this modulus is not available and it is very brittle. There is considered 100 steps for the loaded steps, and load amount is 750 N based on maximum obtained capacity.

TABLE 5.6: RESULTS OF NONLINEAR STATIC ANALYSIS

Sample No.	Analysis type	Displace	Sx (min)	Sx (max)	Sy (min)	Sy (max)	S (von)	Passed step
1	Nonlinear static	0.026	-22	0.44	-31.000	11.3	29.9	100/100
2	Nonlinear static	0.035	-20.9	0.00	-31.500	9.5	29.9	100/100

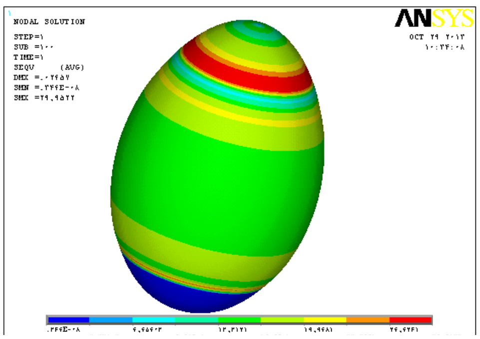


Figure 5.6. Von Maines tension in case 1

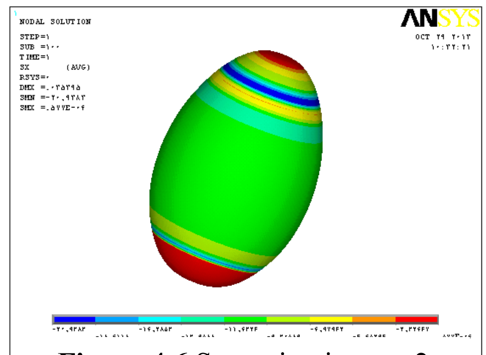


Figure 4.6.S_x tension in case 2

COMPARING EXPERIMENTAL AND THEORETICAL RESULTS

Applying force from both sides cause orthogonal tensile tensions or circuit forces (S_y). Crispy materials in shell (calcareous) cause to crack and failure because they have little resistance against tensile, while compressive forces are well tolerated by shell materials due to two-way curved form. Examining tensions in two cases with length and width ratio 1.5 and 1.7 by using linear and non-linear statistic analysis don't show significant differences between tensions. Figures 1.6 and 2.6 show that volume of tension block (red area) in a case with length to width ratio 1.7 is more than other case. Higher tensile tensions are factors to sooner cracking in comparison with other case. Figures 7-1 and 7-2 show how to beat egg in experimental test and compare with scientific results.

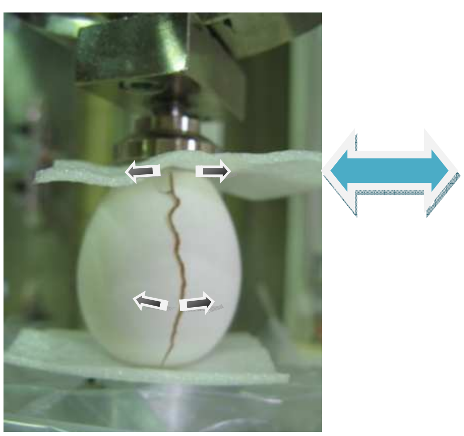


Figure 7.1 .circuit tensile tensions

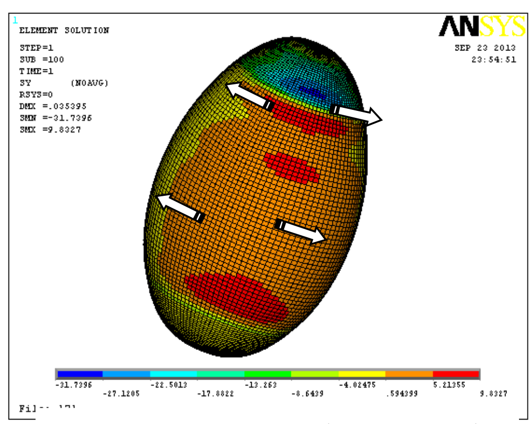


Figure 7.2 .representing egg crack

CONCLUSION

Results show that inside contents of egg don't play an important role in bearing capacity. It is eggshell that plays an important role in bearing capacity and it can tolerate 750 N force by considering the above fulcrum conditions. Creating deep, soft and flexible fulcrums based on egg form, prevent cracking crispy shell and improve possibly of better bearing.

Egg form and geometry play major role in bearing capacity. This form converse load to axial forces, while its bending is negligible. Calcareous materials in shell show appropriate behavior in compressive loads, while it has little resistance to tensile forces, and this causes tension crack in top portion of egg in contact with fulcrum. Developing the crack on fulcrums and its lengthwise growth to both sides will cause cracking egg.

In equal thicknesses, eggs with ratio of length to width 1.5 and 1.7 roughly have the highest and lowest bearing capacity respectively. In this case, the applied load will be converted into orbital and meridional forces. All meridional forces are compressive ones, except some of them in nest place that they are resulted by tension concentration. Some orbital forces are meridional and others are tensile in end of fulcrums. These tensile forces cause to tensile tension and crack in the section, and its developing result to egg cracking.

Practical studies show that shell has low resistance against inner pressure and it is cracked by little pressure. It causes to crack shell quickly and exiting chicken.

Results show that if we design and implement structures' coverage based on an egg-shaped pattern, we can create roofs with small thickness and large openings. Even taking into account orientation and meridional reactions on part of model, it can also be implemented part of the model.

If there is used tensile resistance elements as orbital or angular under shell dealing with tensile forces that cause to crack fulcrum, we will obtain more bearing capacity. This shows role of composite layers. In egg structure, if we use calcareous crystals, which they are connected to inner membranes with appropriate tensile resistance, we will achieve more bearing capacity. Therefore, protein membranes play an important role in composite structure, in addition to its role in defense against bacterial invasion. It can be studied in another research titled "examining resistance of egg structure with composite shell".

REFERENCES

[1]The Holy Quran, SurahA'Ala, 2, 3.

[2]The HolyQuran, Surah Sad, 27.

[3]IranPoultryInstitute, 1999. Complete Guide toPoultry Breeding. M. Farkhooy, T. KhalighiSigaroodi& F.Niknafas, quoted by: http://www.mardoman.net/?id=596&pt=full&sn=articles

[4] EbubekirAltuntas, AhmetSekerog˘luEffect of egg shape index on mechanical properties of chicken eggs, CANADIAN Received 28 May 2007; received in revised form 22 August 2007; accepted 30 August 2007 Available online 24 October 2007.

[5] Ahmed, A. M. H., Rodriguez-Navarro, A. B., Vidal, M. L., Gautron, J.,Garcia-Ruiz, J. M., &Nys, Y. (2005). Changes in eggshell mechanical properties, crystallographic texture and in matrix proteins induced by moult in hens. British Poultry Science, 46, 268–279.

[6] Buchar, J., Nedomova, S., &Simeonovova, J. (2003). Identification of the eggshell elastic properties.ExperimentalniAnaliyzaNapeti.Carter, T. C. (1976). The hen's egg: Shell forces at impact and quasi-static compression. British Poultry Science, 17, 199–214.

[7] De Ketelaere, B., Govaerts, T., Couke, P., Dewil, E., Visseher, T.,Decuypere, L., et al. (2002). Measuring the eggshell strength of 6 different strains of laying hens: Techniques and comparison. British Poultry Science, 43, 238–244.

[8] Voisey, P. W., & Hunt, J. R. (1969). Effect of compression speed on the behaviour of eggshells. Journal of Agricultural Engineering Research,14, 40–46.

[9] P. Coucke*, G. Jacobs*, P.Sasº and J. De Baerdemaeker*, Comparative Analysis of the Static and Dynamic Mechanical Eggshell Behaviour of a Chicken Egg, * : Department of Agro-engineering and -economics, K.U.Leuven, Belgium, º :Department of Mechanical Engineering, division PMA, K.U.Leuven, Belgium.

[10] C. Perianu a,*, B. De Ketelaere a, B. Pluymers b, W. Desmet b, J. DeBaerdemaeker a, E. Decuypere a
a Division MeBioS, KU Leuven, DeptBiosystems, KasteelparkArenberg 30, B-3001 Heverlee, Belgium
b Department of Mechanical Engineering, Division PMA, KU Leuven, Celestijnenlaan 300B, B-3001 Heverlee, Belgium. bi o s y s t ems engi n e e r i n g 1 0 6 (2 0 1 0) 7 9 e8 5. journal homepage: www.elsevier.com/locate/issn/15375110

[11] MacLeod, N., Bain, M. M., Solomon, S. E. and Hancock, J. W. , FAILURE MECHANISMS OF HENS' EGGS, Department of Mechanical Engineering, University of Glasgow, UK, Department of Veterinary Anatomy, University of Glasgow, UK.

[12] Ashley Lloyd, Tara Vaziri, Sam Yang, A composite of crystalline layers and membrane proteins: A mechanical, structural, and compositional investigation of eggshells, April 18, 2011.

[13] Zlatica, P., Vitorovic, D., Lukic, M., &Spasojevic, I. (2003). Improving eggshell quality by replacement of pulverised limestone by granular limestone in the hen diet. ActaVeterinaria (Beograd), 53, 35–40.

[14] Polat, R., Tarhan, S., C¸ etin, M., &Atay, U. (2007). Mechanical behaviour under compression loading and some physical parameters of Japanese quail (Coturnixcoturnix japonica) eggs. Czech Journal of Animal

Science, 52, 50–56.
[15] Jacob, J. P., Milles, R. D., & Mather, F. B. (2000). Egg quality. University of Florida extension, Institute of food and agricultural science, p. 11.
[16] Anderson, K. E., Tharrington, J. B., Curtis, P. A., & Jones, F. T. (2004). Shell characteristics of eggs from historic strains of single comb white leghorn chickens and relationship of egg shape to shell strength.International Journal of Poultry Science, 3, 17–19.
[17] Tung, M. A., Staley, L. M., Richards, J. F., ESTIMATION OF YOUNG'S MODULUS AND FAILURE STRESSES IN THE HEN'S EGG SHELL, CANADIAN AGRICULTURAL ENGINEERING, VOL. 11, No. 1, MAY 1969.
[18] Reissner, E., Stresses and Small Displacements of Shallow Spherical Shells, II. J. Math. , 1947.
[19] M.M. Bain, Eggshell strength : a mechanical/ultrastrucutral evaluation. Ph. D. Thesis,University of Glasgow, Scotland(1992).