VIDEO EXTENSOMETER PICTURE ANALYSIS FOR RUBBERLIKE MATERIALS MODELING

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SUMMARY:

The paper presents a new way of hyperelastic materials specimens testing. For some time now Finite Element Method (FEM) Software allows to calculate stress in this kind of materials which make an engineering work easier. Unfortunately the results of the classical hyperelastic materials tests done so far do not give a possibility to use full abilities of FEM software. Furthermore, the attempts of conversion of classical type of data to FEM expected ones, do not lead to a correct solution. Such input data are accepted by software, but not physically correct. The specimens used for new types of elastomer tests are completely different, they are of different shape, they have to be hold and measured in a different way. These differences are described in the paper.

PROBLEM STATEMENT

All experiments defined by ISO or ASA are the tests which can deliver a lot of important information. Unfortunately most of this information is not appropriate to apply in mathematical material models used by FEM software. Only few laboratories or manufactures give more data then Shore hardness, IRH hardness, abrasiveness, temperature resistance, fluids resistance, oxidation resistance and others defined by standards. Mathematical models are non-linear models, it means that data in numerical form – as one single number representative - is not usable. Expected data is a set of stress/strain functions in discrete form (Fig. 1). Such tests are provided, but in a different way than expected. Most popular in this group of tests is the simple tension test.

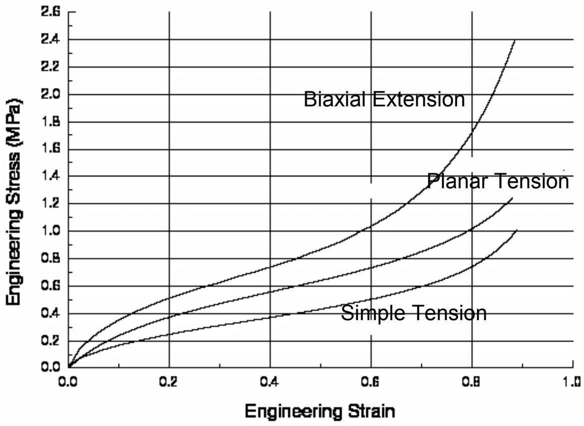

Fig. 1 A typical final data set for input into a FEM software in discrete form.

The simple tension test in a classical way is made on the bone shape specimen. This way of testing, especially when the standardized wide/length ratio of specimen is low, is very imprecise. The problem is that measure points are the clamps. Even when you

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use modern measuring tools the border width between measured area and clamp area is very significant in proportion. Furthermore, even if a simple tension test is done in a laboratory, the result is given as a tensile strength, extension by break off, and stress by 100%, 200% and 300% extension. That is not enough to make approximation of real curve. The other way of simple tension test is a measurement of tension of an elastomer ring (Fig. 2). This test is better than dog-bone style specimen, but also the clamp area is very significant.

Not as widely used is the compression test. This one is performed using specimens in cylindrical shape.

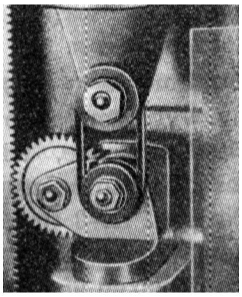

Fig. 2 Test of an elastomer ring tension

In this test one does not have any problems with measuring, you just measure a distance between compressing plates, but all other problems described in the tensile case are still valid. Also load imputation is a problem, when you achieve pure uniaxial compression.

Fig. 3 Compression test

In the first phase of an experiment on a top and a bottom of a specimen appear cones where is no deformation (Fig. 4A) because of friction which holds this part of the specimen motionless. Everywhere else you can see a pure compression. One moment later appear shear effects and characteristic shape of a barrel (Fig. 4B). Subsequently, the cones contact each other and compression force is suddenly growing. In most cases the tests are conducted until phase “C” [Jaroszyñska 1978].

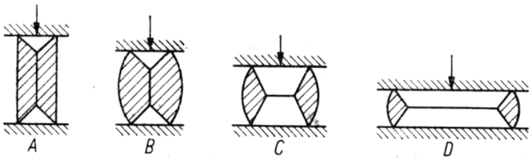

Fig. 4 Compression test pattern

Because of friction there is not only a pure compression (Fig. 3), but also shear and tensile. Even though most of elastomers in industry are sheared, the rarest conducted test from physical properties tests group is a shear test. What more, there are several different ways of shear testing. Representative for a non FEM aim is a test of four elastomer plates between steel plates as shown on Fig. 5.

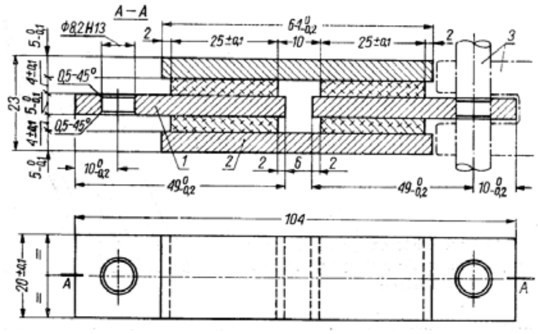

Fig. 5 Specimen for a shear test

PROBLEM SOLVING

Each of the tests described previously has its equivalent in a form designated for FEM. The shear test, recommended by many authors, is a test which completely doesn’t look like a shear test (Fig. 6). At a first glance the experiment appears to be nothing more than a very wide tensile test. However, as the material is nearly incompressible, a state of pure shear exists in the specimen at a 45 degree angle to the stretching direction. The most significant aspect of the specimen is that it is much shorter in the direction of stretching than wider.

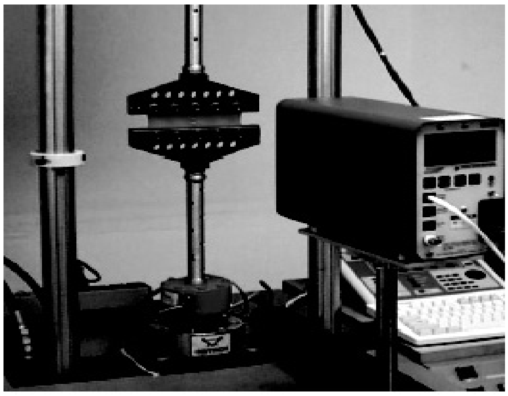

Fig. 6 Shear test

The objective is to create an experiment where the specimen is perfectly constrained in the lateral direction in a way that all specimens thinning occur in the thickness direction [Osiński, Amborski 2004].

Finite element analysis of the specimen geometry shows that the specimen must be at least 10 times wider than the length in the stretching direction.

This experiment is very sensitive to this ratio. A non contacting strain measuring device must be used to measure strain away from the clamp edges where the pure strain state occurs.

The compression test performed in the same way as the one described above is allowed, but only when you know already all other data, it means shear curve, pure tensile curve and pure compression curve. In this case you can use this test to calculate a friction coefficient between specimen and plates. Even small friction may cause substantial shearing strains that alter the stress response to straining (Fig. 7). Often, the maximum shear strain exceeds the maximum compression strain.

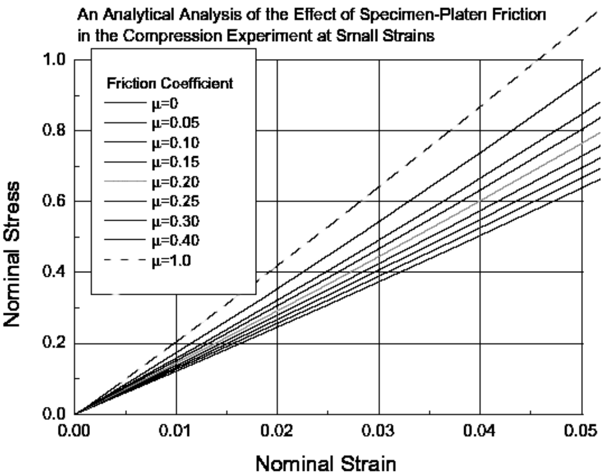

Fig. 7 Friction effects on stress-strain curves at low strains.

Another experiment that also provides compression information is the equal biaxial extension experiment. This may not seem obvious at first glance. However, as an elastomer is radial strained in all directions in a single plane as shown in Figure 8, the free surfaces come together. For incompressible materials, the state of strain in the material is the same as that in simple compression and free from friction. The measured experimental parameters are the radial strain and the radial stress.

As an academic exercise, these biaxial strains and biaxial stresses can be converted directly to compression strains and compression stresses as follows:

$$\sigma_c = \sigma_b\,(1 + \varepsilon_b)^3$$
$$\varepsilon_c = 1/\,(\varepsilon_b + 1)^2 - 1;$$

where:
σ_c is nominal engineering compression stress,
σ_b is nominal biaxial extension stress,
ε_c is nominal engineering compression strain,
ε_b is nominal biaxial extension strain.

Typically it is not necessary to do this conversion because most curve fitters accept equal biaxial extension data directly. As with the compression experiment, analysis of the equal biaxial extension specimen is necessary to examine its suitability.

An additional advantage of using equal biaxial extension in place of simple compression is that the biaxial extension specimen can be cut from the same sheet of material as the simple tension and pure shear specimens while most compression specimens need to be molded separately. By cutting all specimens from the same sheet, consistent material properties and therefore a consistent data set can be developed.

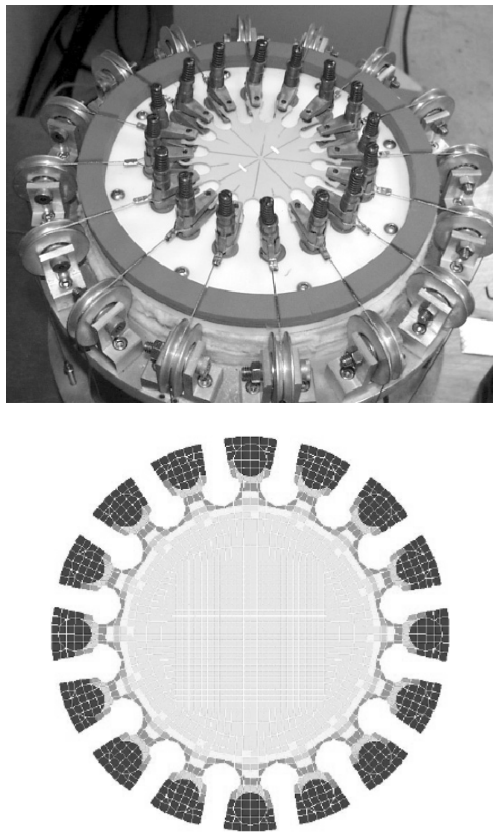

Fig. 8 The biaxial extension experiment using a laser extensometer

The test described as a first one in this paper was the simple tension test. Also for a FEM such a test is very important because tension is not just a mirror opposite to the compression. The difference is in the shape of specimens. However, the experimental requirements for analysis are somewhat different than most standardized test methods. The most significant requirement is that in order to achieve a state of pure tensile strain, the specimen is much longer in the direction of stretching than in the width and thickness. One can perform finite element analysis on the specimen geometry to determine the specimen length to width ratio. The results of this analysis show that the specimen needs to be at least 10 times longer than the width or thickness.

Since the experiment is not intended to fail the specimen, there is not a need to use a “dog-bone” shape specimen. There is also not an absolute specimen size requirement.

The length in this case refers to the specimen length between the instrument clamps. Specimen clamps create an indeterminate state of stress and strain in the region surrounding the clamp in the process of gripping. Therefore, the specimen straining must be measured on the specimen, but away from the clamp, where a pure tension strain state occurs. A non-contacting strain measuring device, such as a video extensometer or a laser extensometer, is required to achieve this aim. The wire tensile tests are used as well.

VIDEO EXTENSOMETER

In comparison to steel hyperelastic materials can not be tested using classical contact extensometer. There are two main reasons for this. Firstly, a much more complicated way of force input into specimen and clamp influence. The second reason is the pressure of the extensometer on the specimen, which is negligible in case of steel, but may be significant in case of elastomers. There are two types of non contact extensometers – laser extensometer and video ekstensometer. Laser extensometers are not useful for elastomer deflections because of small measurement range. Thanks to constant growth of photo matrix technology, matrixes’ current resolution allows to make them a measuring tool in video extensometers.

Principle of operation and possibilities

The principle of video ekstensometr operation is exposure of the markers on the digital photo matrix and calculation of photo elements between them. Such a discrete picture is analyzed by computer program. First the histogram of the picture is made. Using histogram the two maxima are found – background lumination and markers lumination. The markers pixels are counted. The first source of inaccuracy is the lens, the second is the matrix. Both of them have finite resolution. The lens gives a possibility of arbitrary change of the measure range by changing the focal length. This change does not influence the constant precision of the matrix.

The method allows analysis of more than one dimension simultaneously, which makes it possible to measure Poisson ratio or Cauchy stress.

One of the advantages of measuring by analyzing a picture is a possibility of synchronization force and strain readings. In case of strength testing machine with digital output it is obvious. But if strength testing machine does not have digital output, one can also make the measurement putting the indicator in the camera field of view. Then one can start a computer program to analyze also this picture.

Depending on the resolution of the matrix used, scanning frequency, speed of the analyzing procedure and speed of the deflection one can have a result in real time or after the test is finished. The problem with real time results will always exist because along with the increase of the processor speed the resolutions of the matrix and number of data to analyze also increase.

Modification Offer

Video extensometers used until now analyze a distance between contrasting borders of markers. This method is very sensitive to nonlinearity of the markers borders. During following shots it is possible, that such edge will be considered for analysis by software in other way than in previous shot and the measurement will be incorrect. Using this method it is also necessary to use very clean specimen in optical sense. It can occur that in some shots some dust on specimen can be interpreted as edge, causing also incorrect results.

The offer is not to analyze a distance between borders, but a distance between centers of gravity of markers surfaces. First of all such a measurement has double precision, secondly sensitivity to non-regular shape of markers is much lower. The markers may be just track after ball pen. That kind of picture analysis procedure finds the biggest blurs and only those are taken into consideration. It is the way, by which also low contrast pictures and with a lot of dust may by analyzed.

Fig. 9 shows a window of a program which compare different algorithms for picture analyze. The same program analyzes speeds of the algorithms.

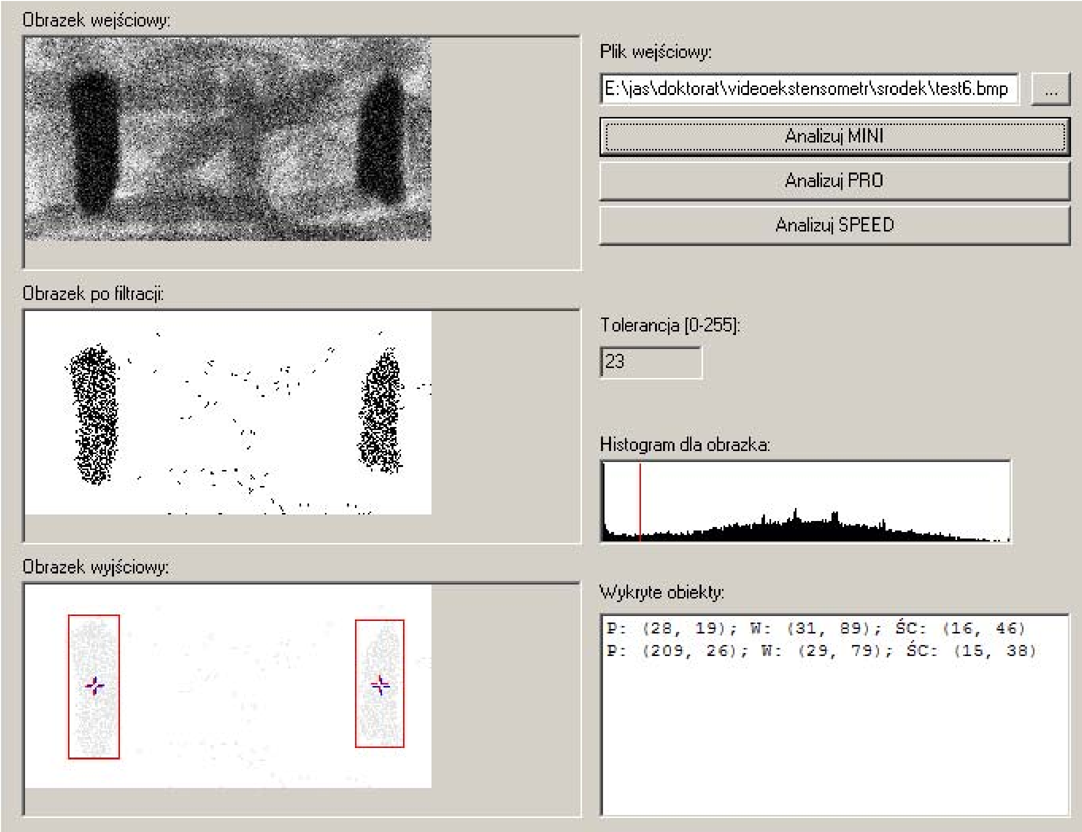

Fig. 9. A window of program which compares different algorithms for picture analysis.

The next modification is a multiplication of resolution in beginning phase of a measurement.

The photo matrix, which is a measurement element, is made of single photo elements regularly distributed along the entire matrix. It means that when there is a big deflection during the measurement, at the beginning phase of the measurement, only few elements take part in the measurement with nominal precision. The more elements are between markers, the more precise the measurement is.

It is suggested to measure complete deflection dividing it in phases, which will be measured using different focal lengths to use as many elements as possible and get constant precision during the whole measurement.

Such a video extensometer is called transfocal video extensometer. The result of such measurement is a set of curves which are matched using C2 continuity. The low precision in glue points are compensated by multiplicated precision in the rest part of the measurement. The patent for this solution is pending.

CONCLUSIONS

Although both ways of testing hyperelastic materials are very significant and useful data are gained, the newest one seems to be more accurate, especially because of possibility of making most of specimens from one piece of material and because experiments are more clearly divided – one experiment, one pure strain state, one variable measured. On the other hand hyperelastic materials are commonly used to damp vibrations. Energy is absorbed because the load characteristic is different from unload characteristics. You may calculate this energy using damping coefficient, but not in classical FEM. In FEM the load and unload characteristics are the same, nowadays.

REFERENCES

Amborski J., Kajka R. - "Application of Finite Elements Method for Analysis and Design of Hyperelastic Material". ESM 2002 Conference, Darmstadt (Germany)

Amborski J. - „Modelowanie tłumików drgań z materiałem elastomerowym z zastosowaniem MES." (Modeling vibration elastomer dampers using FEM) Doctor Thesis, Warszawa 2006

Osiński J., Amborski J. - "Elastomer Tests for finite Element Analysis Application", Proceedings of the XVI Polish-German Seminar, Development Trends in Design of Mechanics and Vehicles, Warszawa, June 2004, s. 103 – 110

Dacko A. - "Analysis of Elastometric Structural Components." 2000 - V KWPI Conference, Polanica Zdrój 2000, Poland. s. 253-262

Ogden R. W. – „Nonlinear Elasticity with Application to Material Modeling", Institute of Fundamental Technological Research, Polish Academy of Sciences, Lecture Notes 6, Warsaw 2003

Jaroszyñska D., Gaczyñski R., Felczak B. - "Methods of Rubber’s Physical Properties Tests", PWN Warsaw, Poland 1978

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