# EXPERIMENTAL IDENTIFICATION OF HYPERELASTIC MATERIAL PARAMETERS FOR CALCULATIONS BY THE FINITE ELEMENT METHOD

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***Abstract***

*Elastomer materials are commonly used in manufacture of parts of machines and vehicles. A numerical analysis of these elements is possible with many calculation methods, however, due to such properties as incompressibility, very often large deformations, non-linear constitutive compounds, friction and contact phenomena, an analysis by the finite element method turns out to be a very complicated task.*

*The purpose of experimental studies which were carried out was to determine parameters of hyperelastic materials used for production of elastomer tracks for industrial vehicles. Experiments were carried out with rubber test samples of the hardness close to the hardness of materials used for manufacture of rubber tracks, lining of the driving wheels and track rollers. These parameters were determined for models of hyperelastic materials (Mooney-Rivlin) used for calculations. The obtained results were compared by numerical calculations with the help of the finite element method with a model sample at identical load conditions for various models of a material including a material of linear properties (of the constant Young's modulus).*

*Obtained results of studies and numerical analyses demonstrate only a limited potential of the use of linear models for hyperelastic materials – this use is possible only at small deformations. Obtained results of measurements and analyses can be used for proper modelling of parts made of elastomer materials.*

**Keywords:** *finite element method, elastomer, experimental identification*

## 1. Introduction

Structural elastomer materials used for many years (to manufacture e.g. sealings, tyres, linings of friction transmission wheels etc) call for a different description than materials modelled as linear-elastic (e.g. steel). Non-linear constitutive compounds, large relocations and material incompressibility are the reason why numerical calculations by numerical methods (e.g. FEM) for the analysis of loads on elements made of elastomers (e.g. rubber) are among the most complicated. A proper set of data describing the material behaviour under load is one of essential factors affecting the correctness of results of such numerical analyses.

Rubber defined as a hyperelastic material (Mooney [1], Rivlin [2], Ogden [3]), which can be deformed elastically within a very wide range up to several hundred percent, is the most commonly used incompressive elastomer. A feature characteristic for rubber-based materials of a practical incompressibility causes the Poisson ratio to be close to 0.5 (while practically assumed values are: 0.48-0.5).

## 2. Numerical modelling of hyperelastic materials

Numerical analyses with the help of the FEM require a mathematical definition of material properties in the form of the relationship between the deformation and the stress. In case of isotropic and uniform materials, satisfying the Hooke's law, only two parameters, the Young's modulus and the Poisson ration suffice to characterise these properties. For modelling hyperelastic materials one assumes the postulate of the existence of the functional of the material deformation energy density, which depends on certain parameters characterising the state of deformation. In practical applications there are usually two forms of the deformation energy density functional depending on the parameters, which are characteristic for the deformation state; these are the deformation tensor invariants $I_1$, $I_2$, $I_3$ or the deformation tensor eigenvalues $\lambda_1$, $\lambda_2$, $\lambda_3$.

Models based on the form of the deformation energy density functional, with this deformation energy depending on the deformation tensor eigenvalues, are represented by the Ogden [3] model, which by assumption takes into account a certain compressibility of a material.

The Mooney'a-Rivlin model most often used for modelling of rubber elements, a part [1, 2] is based on the invariant form of the deformation energy density functional, and in its original form assumes a material is incompressible. This is a multiple-parameter model of constant coefficients with which we can describe actual material characteristics for different kinds of rubber. The number of parameters required to describe a material [2, 5 or 9] depends on the shape of characteristics obtained from deformation tests under load, e.g. during stretching.

## 3. Determination of material characteristics for FEM analysis

Types of tests for determination of various material characteristics are shown in Fig. 1.

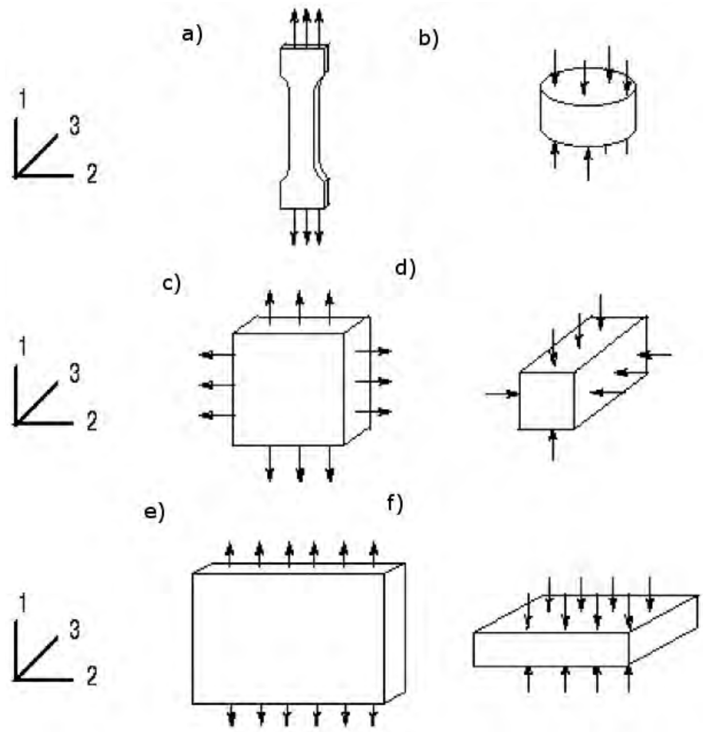


*Fig. 1. Test methods for determining material properties*

Depending on the selected analysis to determine necessary material parameters (for a selected calculation model) adequate experimental testing must be carried out. Tension tests, which are most common (Fig. 1a) in case of other deformation states, e.g. compression (Fig. 1b) do not suffice. In the event of an incompressible material, e.g. in case of rubber-based elastomers, which can be regarded as such, parameters obtained from the compression test depend on the area of the so-called free surface of an element under deformation, or as matter of fact, on the relation of the loaded surface of an element to the unloaded surface of this element. Depending on this definition of the shape coefficient and on the rubber stiffness obtained values can vary significantly. Very non-linear FEM analyses can be very sensitive to the quality of entered data, therefore experimental testing including multi-axial load states including shearing must be carried out.

## 4. Experimental testing

Studies were conducted with elastomeric materials used for production of elastomer tracks of industrial vehicles. Apart from the hardness no other properties of rubber were known. Analyses were carried out for uniaxis compression and uniaxis tension. Experimental tests were carried out at room temperatures with standardised test samples [4, 5]; flat (for tension) and cylindrical (for compression) at a tension-testing machine with which deformations of test samples at speeds as prescribed by standards [4, 5] were possible.

a) Uniaxis tension

Three test samples of the type 1 [4] (basic shape of a tensile dog bone) were tested and on the basis of obtained results an averaged relationship: stress – deformation was determined; as shown in Fig. 2.

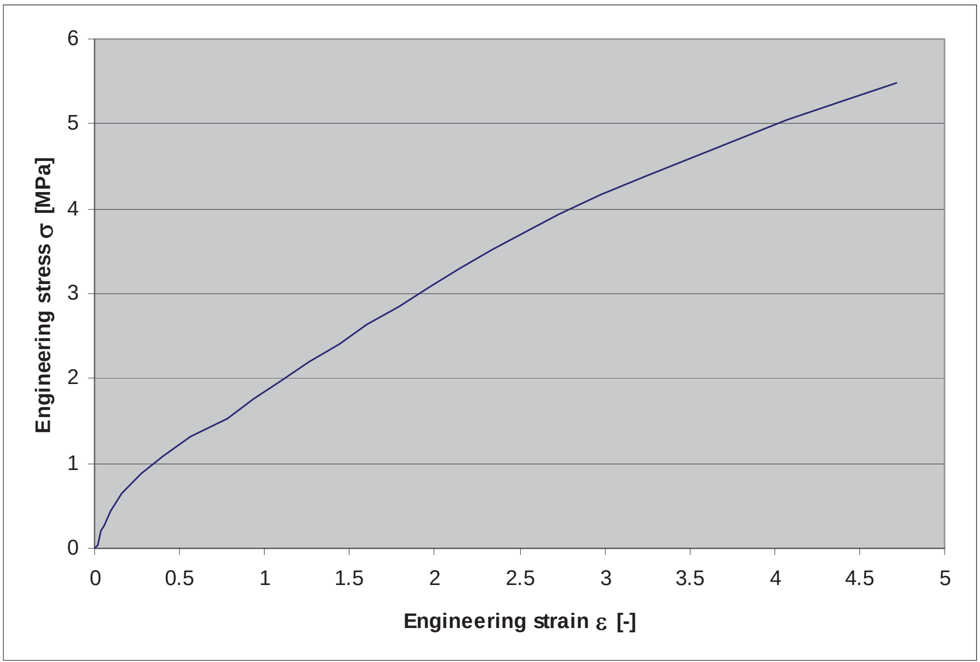


*Fig. 2. Averaged relationship σ-ε obtained by uniaxis tension*

b) Uniaxis compression

In a similar way as above, tests were carried out on three cylindrical samples according to the standard [4] and for further calculations results recorded for the fourth deformation of the sample were used. Fig. 3 presents an averaged relation stress - deformation for compression.

To determine parameters of the hyper elastic material model one has used a function implemented in the ABAQUS [6] software; a function, which basing on entered data allowed to automatically obtain coefficient values for a selected constitutive law. In the analyses which were carried out one decided to apply the most common Mooney-Rivlin model and for these model coefficients were determined, which characterise a hyperelastic material tested in experiments. The extent to which the used model matched the obtained parameters is shown in Fig. 4.

Obtained parameters of the model were verified by comparing experimental testing data against data from numerical calculations. To this end one has constructed a numerical model of cylindrical test sample (Fig. 5), and this model was subjected to loads corresponding to conditions at a tension-testing machine. Some parameters of FE model: element type: solid (continuum) 4-nodes tetra, load: pressure on top plane of test sample corresponding to applied force on the tension-testing machine, constraints: nodes on bottom plane has fixed dislocation along vertical axis, boundary condition: in FE model passed over friction between test sample and parts (steel planes) of tension-testing machine, material: nonlinear, hyperelastic (Mooney-Rivlin model).

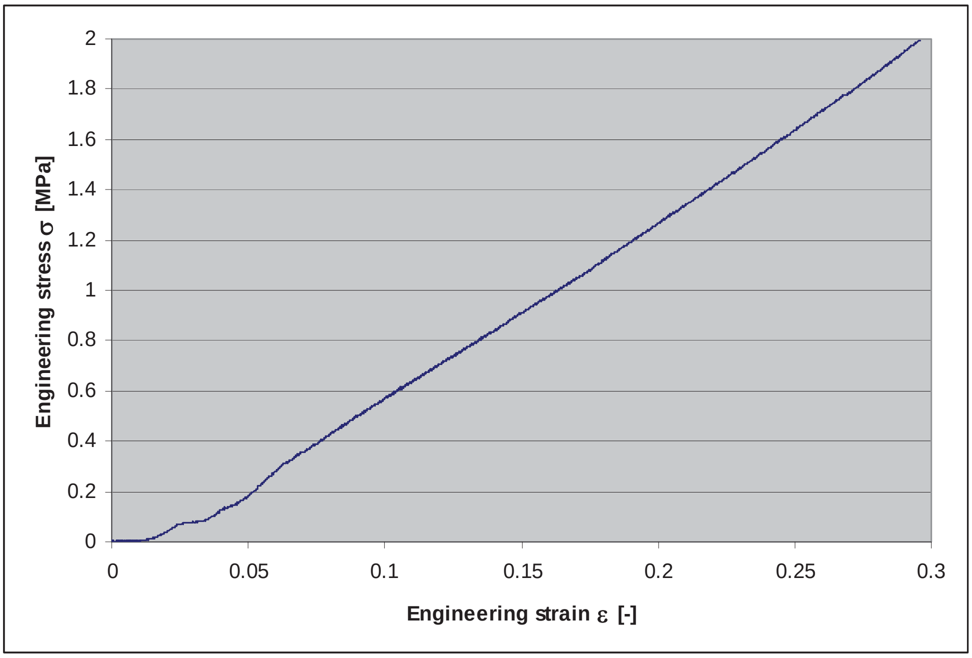


*Fig. 3. Averaged relationship σ-ε obtained by uniaxis compression*

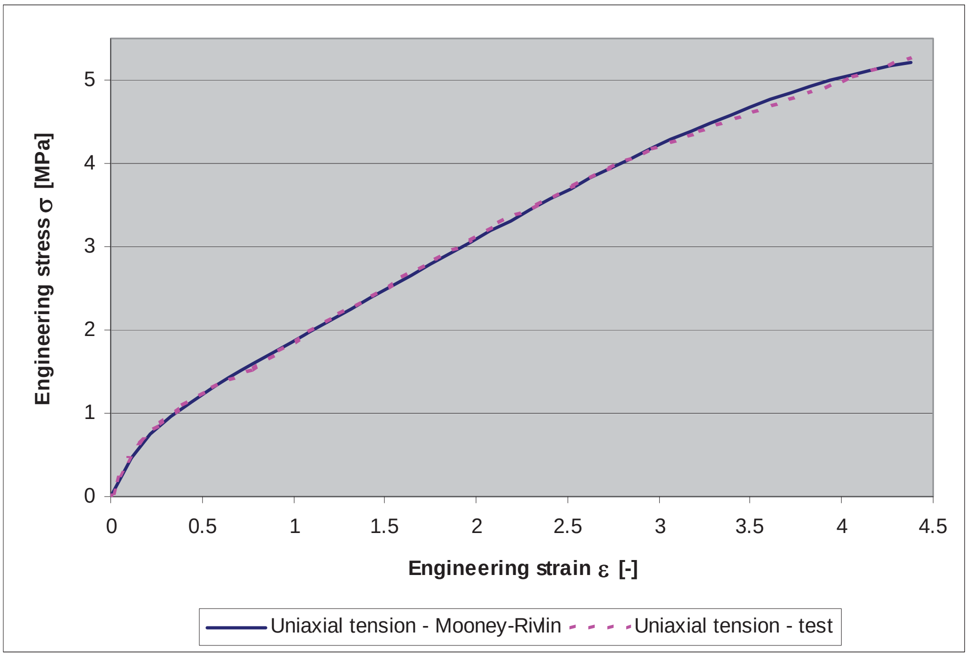


*Fig. 4. Curve fit from ABAQUS software by uniaxis tension*

Numerical model were prepared with the NE/Nastran.Modeler and the numerical analyses were carried out with the ABAQUS programme. Fig. 6 shows numerical calculation results against experimental testing results.

The analysis by the FEM with a test sample subjected to tension (dog bone, a 2D-plane stress analysis), however, assuming constant Young's modulus (a linear elastic analyses) demonstrates (Fig. 7) that at deformations greater than 0.1, a liner model does not reflect the sample behaviour properly.

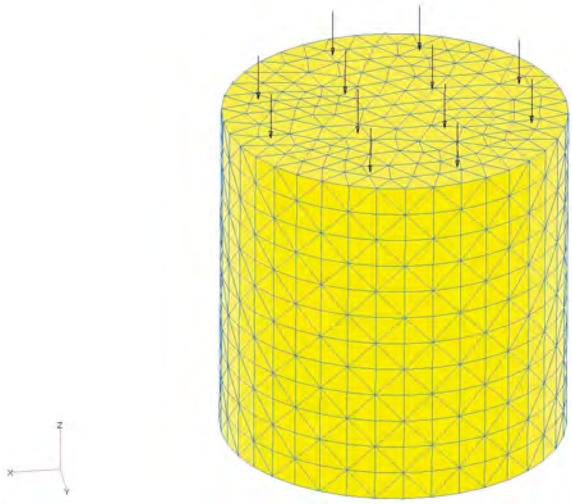

*Fig. 5. Finite element model of cylindrical test sample*

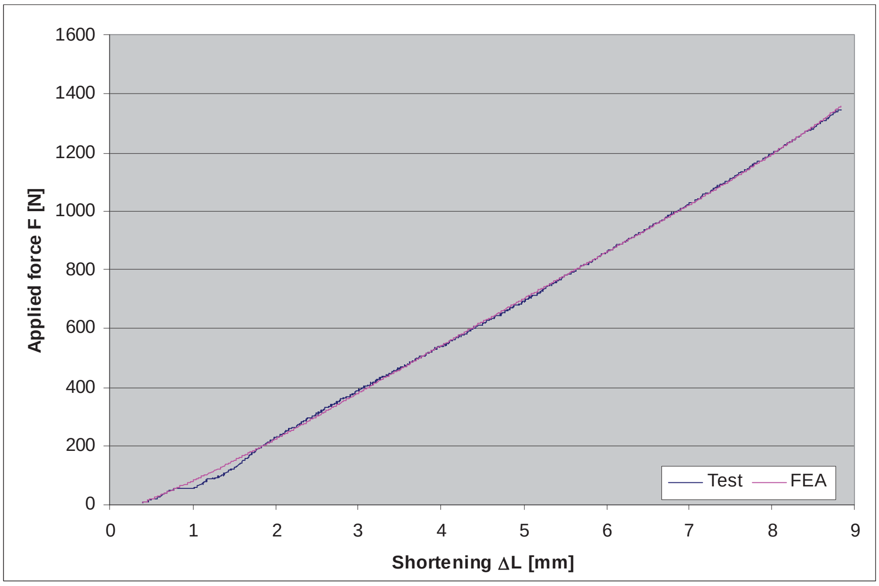


*Fig. 6. Comparison of experimental and finite element models*

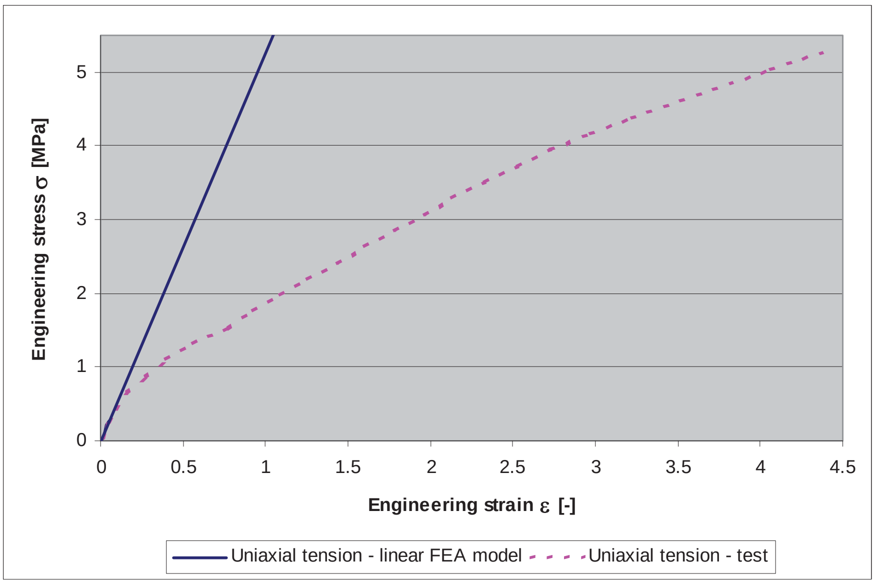


*Fig. 7. Comparison of experimental and linear finite element model (tensile dog bone sample)*

## 5. Conclusions

Small strain analysis using linear elastic material properties would produce acceptable results, but as the engineering strain increases past 0.1 the errors increases rapidly.

In case of non-linear analyses results obtained from numerical calculations depend very much on the quality of entered material data, which can be gained only by way of experimental testing. They can also serve to verify data quoted by material manufacturers.

## References

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