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Determination of Material Parameters of Rubber and Composites for Computational Modeling Based on Experiment Data

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Introduction

The topic and content of this paper, which deals with the determination of the Mooney-Rivlin material parameters of elastomers (rubbers) based on experimental data hardness Shore A and the determination of the modulus of elasticity of composites with elastomer based on experimental data, is also current in terms of the needs and requirements of the tire industry not only in Slovak Republic because the results from the project can be applied for the development of tire casings for modern passenger cars and trucks as well as for production of the products relating to other areas where they can be used appropriately (e.g. conveyor belts). The results can be used as input data to computational modelling of composite materials with elastomer matrix [1, 2] and new-generation tires.

For the description of elastomer parts of tire-casings there are used several material models of the viscoelastic behavior of the material – constitutive models, the Mooney-Rivlin (MR) model is the most used. MR parameters can be determined based on the Shore A hardness.

Research methodology

The Shore A durometer is used for hardness measurement of elastomer. Following equations can be used conversion of the mentioned hardness. These equations can lead to different results of moduli for the same Shore A hardness.

- Gent equation:

$$E = \frac{0.0981\cdot(56+7.62336\cdot A)}{0.137505\cdot(254-2.54\cdot A)} \qquad (1)$$

- equation [3]:

$$E = exp(0.0235\cdot A - 0.6403) \qquad (2)$$

- equation [4], the elastic modulus is expressed in [psi]:

$$E = 11.427\cdot A - 0.4445\cdot A^2 + 0.0071\cdot A^3 \qquad (3)$$

- Batterman/Köhler equation based on expression dependence between shear modulus and Shore A:

$$G = 0.086\cdot 1.045^A \qquad (4)$$

The test machines Hounsfield H20K–W and Shimadzu Autograph AGX plus 5 kN are used for tests of composites. There are used a method based on 0–8 %, 4–8 %, 0–10 % and 4–10 % strain. The last method is based on reading values of the linear part of dependence.

As a sample, the calculations of moduli of elasticity are made on 5 specimens (Fig. 1) with a different two-layer steel-cord belt of a radial tire casing. The specific initial conditions of static tensile tests are: the speed of loading 10 mm/min, the initial length of specimen is 80 mm between the clamps.

Figure 1. Specimens after tensile tests.

Results

Tables 1 show the calculated moduli for Shore A hardness of 80, MR parameters as well as parameter of incompressibility. It is important to point out that C_{01} parameter is 0.2 multiple of C_{10} parameter.

The resulting MR parameters have to be verified because this is the only one possible way how to find out the most suitable equation for the given application. The mentioned fact is the reason for creation of FEM computational model of interaction between indenter and elastomeric material. The given model is used for simulation of hardness testing process by Shore A method.

The computational model of interaction between indenter of Shore A durometer and elastomer samples is on the Fig. 2. There is an example of the strain of tested elastomeric sample and it is based on definition of MR parameters, which were calculated by help of equation with designation as (1) and it was for hardness of 80.

The stress-strain dependences for obtain of moduli of elasticity are in Chart 1. in the Table 2 are the results of the moduli of elasticity by method 4–8 %.

Table 1. Shore A hardness of 80, Poisson's ratio ν = 0.4995.

Equation	E [MPa]	G [MPa]	K [MPa]	C_{10} [MPa]	C_{01} [MPa]	C_{10} - C_{01} [MPa]	d [MPa^{-1}]
1	9.3513	3.1181	3 117	1.5590	0.3118	1.2472	0.00064
2	3.4545	1.1519	1 151	0.5759	0.1151	0.4607	0.00173
3	11.7525	3.9188	3 917	1.9594	0.3918	1.5675	0.00051
4	8.7252	2.9093	2 909	1.4546	0.2909	1.1637	0.00068

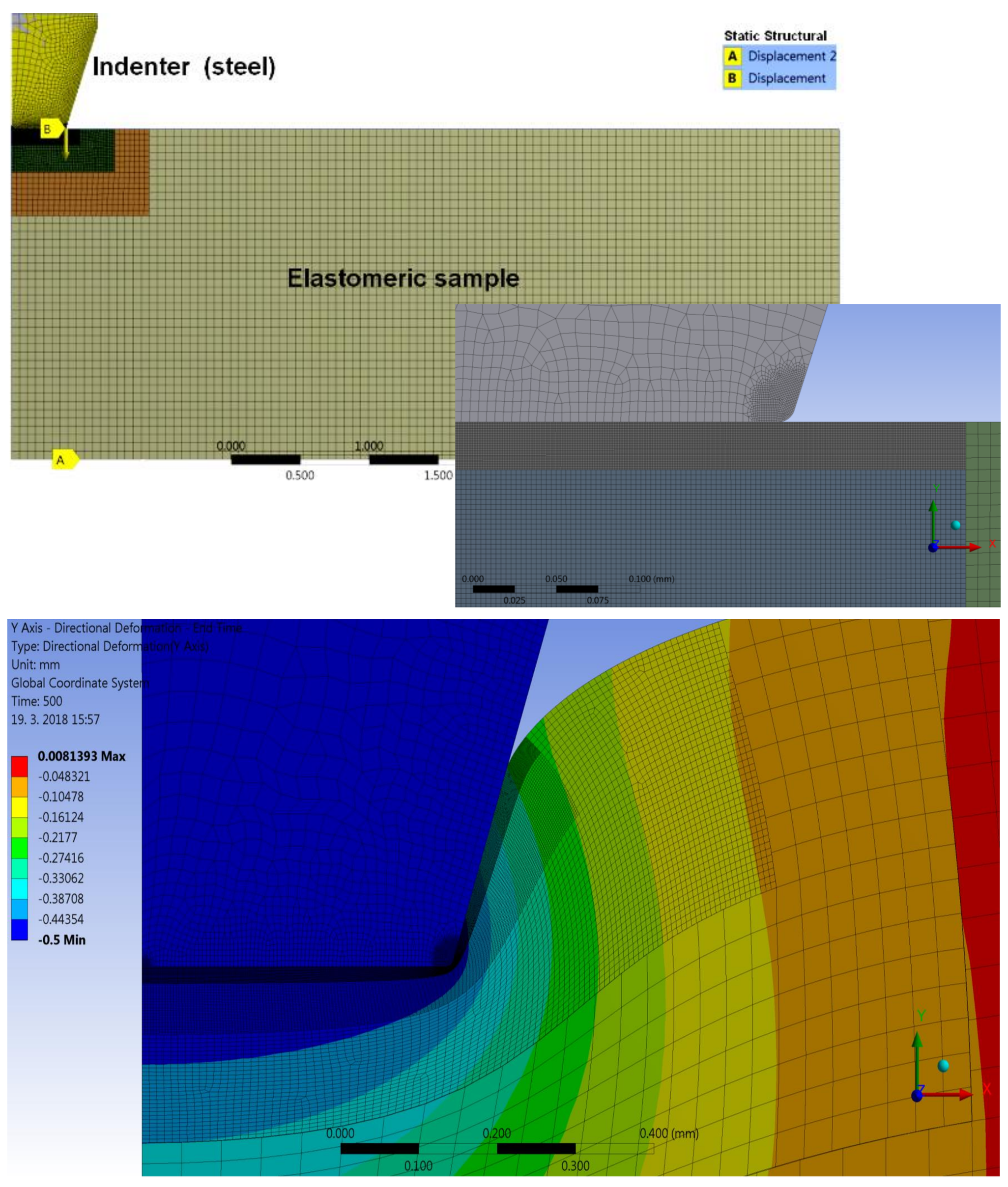

Figure 2. Computational model for verification of calculated MR parameters (with contact area between indenter and tested elastomeric sample) and below = the displacement filed of the tested sample after indenter displacement by 0.5 mm [5].

Table 2. Moduli of elasticity for specific tire composite structure specimens.

Specimen No.	E [MPa]
1	218.5
2	53.6
3	380.9
4	65.5
5	151.7

Conclusions

Based on the obtained results, it can be concluded that we recommend to use Gent equation (with designation as 1) for calculation of MR parameters for hardness of 80.

The verification of the calculation is very difficult because we do not have the results of calculations of modulus of elasticity for these specific composite specimens by other methods, whether from static tensile tests, or other such non-destructive methods of determination of the modulus of elasticity using other test equipment.

The evaluation of various methods, it was concluded that the most appropriate method for determination of the moduli of elasticity is method of 4–8 % elongation.

The results can be used as input material data of rubber seals of pump and compressor machinery for their computational modeling.

The specific low-cyclic tensile tests of tire textile carcass [6] are also important for obtaining material parameters too. Further research work will be focused on tests of cyclic loading of composites using uniaxial and biaxial tensile loading at different temperatures with determination of material parameters such as moduli of elasticity for computational tire simulations.

References

1. Krmela, J.: *Tire Casings and Their Material Characteristics for Computational Modeling*. Scientific monograph. Printing House the Managers of Quality and Production Association Czestochowa, Poland. ISBN 978-83-63978-62-4 (2017).
2. Krmela, J., Krmelová, V.: Tire Casings and Their Material Characteristics for Computational Modeling of Tires. In: *Engineering for Rural Development : 16th International Scientific Conference*. 230–235 (2017). 10.22616/ERDev2017.16.N043
3. Reuss, B.: Convert Durometer to Young´s Modulus. (2011) Available at: https://www.cati.com/blog/2011/07/convert-durometer-to-youngs-modulus/
4. Mooney Rivlin Constants, (2005). Available at: http://xansys.org/forum/viewtopic.php?p=51617&sid=609a8612c34eb2eec373756fd062aea2
5. Kvasnica, T.: *Examination of Designed Structure Used for Weightlifting in CrossFit by FEM* (In Slovak), Diploma thesis, Faculty of Industrial Technologies, Alexander Dubcek University of Trencin, Puchov (2018)
6. Krmela, J., Krmelová, V.: Dynamic Experiment of Parts of Car Tyres. *Procedia Engineering* **187**, 763–768 (2017). 10.1016/j.proeng.2017.04.435

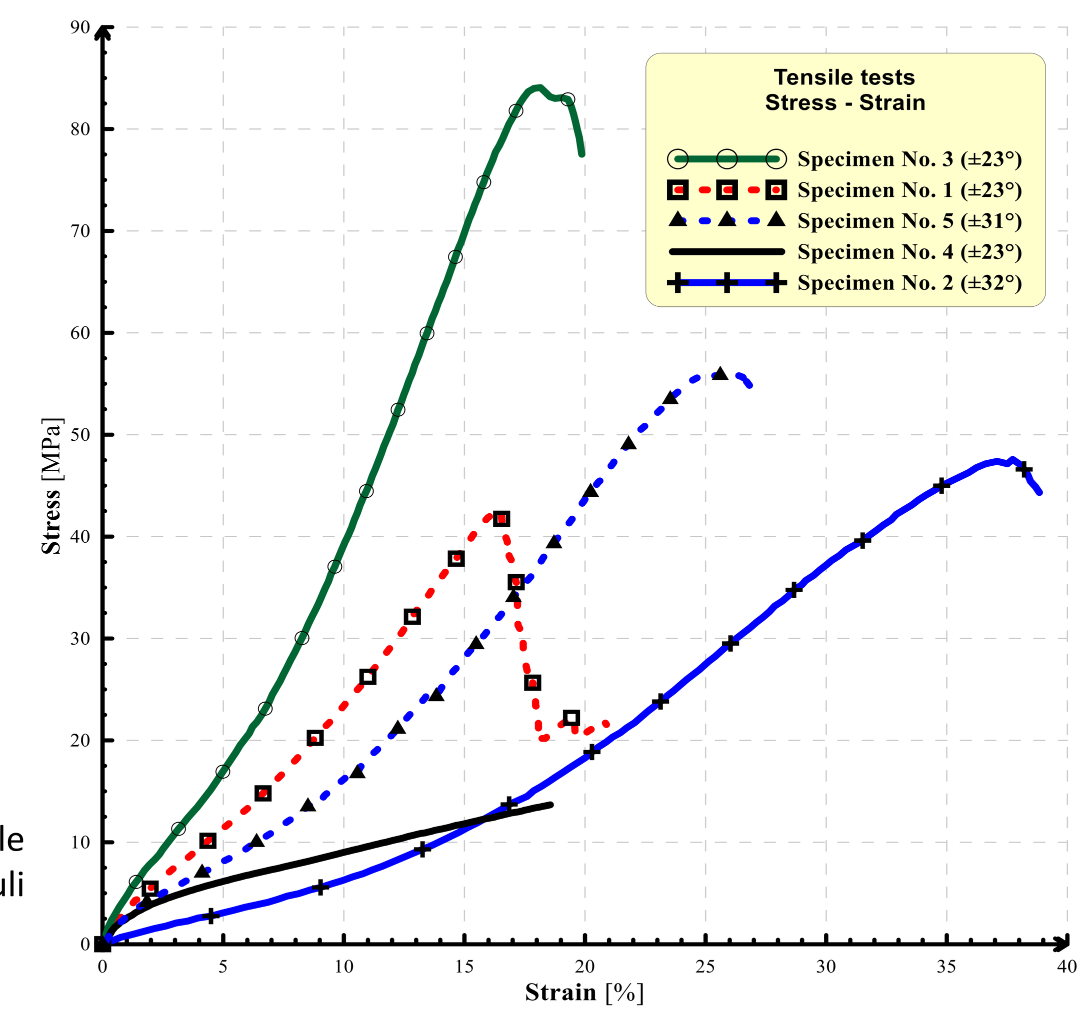

Chart 1. Stress-strain dependences from tensile tests of composite specimens for obtain of moduli of elasticity.

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