"CHARACTERIZATION AND MODIFICATION OF MECHANICAL PROPERTIES OF HYPERELASTIC RUBBER"

B. LAPČÍKOVÁ, L. Lapčík Jr., M. Vašina, , P. Smolka

Tomas Bata University in Zlin, Institute of Physics & Material Engineering,
Nad Stráněmi 4511, CZ – 760 05 Zlín, Czech Republic
e-mail: lapcik@ft.utb.cz, web: www.ft.utb.cz/czech/UFMI
Phone: +420 57 603 5115, Fax: +402 57 603 5141

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Ruber, hyperelasticity, mechanical properties, biaxial tensile testing, FEM calculations

Introduction

Not-filled rubber has a similar modulus of elasticity K as polymer glasses. However, they differ with respect to them in several points:

1. Their Poisson ratio is close to 0.5. Consequently, the modules E, G are much lower than K. Normal value of E non- rubber is the order of 10^0 MPa (10^{-3} GPa).
2. The work expended on deformation of the rubber is almost completely transformed into heat.
3. Equilibrium modulus of elasticity is proportional to absolute temperature.

Dependence of shear stress on shear deformation of rubber is almost linear. The curve expressing the dependence of stress on deformation in compression is nonlinear, deflected upwards. Shear modulus is almost equal to the third module E, Poisson ratio is very close to 0.5.
Elongation increases with increasing level of network creation process. Elongation with increasing degree of cross-linking decreases monotonically, strength initially increases, reach a peak value and then decreases. Stress increases with increasing direction in the area above the tensile curve inflection point. Length of the tensile curve inflection point and thus the value of strength and elongation is the greater the greater degree of orientation crystallization is present in the material structure.
Time (relaxation) phenomena in the range of small and medium deformations in filled natural rubber (at room temperature) are characteristic of almost negligible hysteresis. In the area above the inflection point there is observed a large hysteresis. It is caused by orientation crystallization.
These phenomena are described by the phenomenological theory of rubbery elasticity. Mooney-Rivlin equation (MR) is describing a tensile curve of rubbery networks very well to the inflection point.

$$\sigma_{xx} = \frac{F}{A_0} = 2C_1\left(\alpha - \alpha^{-2}\right) + 2C_2\left(1 - \alpha^{-3}\right) \quad (1)$$

The parameters C_1, C_2 are evaluated from experimental data. From these equations follows the expression for elastic modulus:
$E = 6C_1 + 6C_2$; $G = 2C_1 + 2C_2$ (2)

Experimental

Materials and methods:
Tested samples of EPDM and NBR rubber were present in the form of plates having dimensions of (180 × 160 × 6) mm resp. (180 × 160 × 2) mm. Tensile testing and biaxial tensile testing was performed on Shimadzu Autograph AG-X and 3D Optical Deformation Measurements – 3D ARAMIS.

Results and discussion

Measured stress-strain dependences for different deformation rates are shown in Figs. 1 and 2.

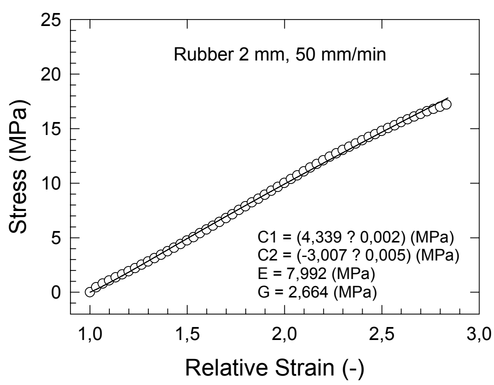

Fig. 1. *Stress strain dependence for rubber plate 2 mm thick for deformation rate 50 mm/min. Full line – results of the calculation according to the model (1).*

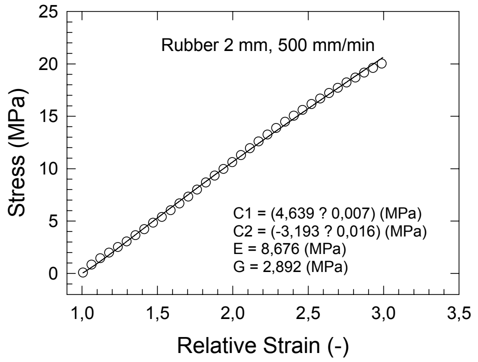

Fig. 2. *Stress strain dependence for ruber plate 2 mm thick for deformation rate 50 mm/min. Full line – results of the calculation according to the model (1).*

Obtained Mooney-Rivlin parameters were used for FEM calculations. TG DTG experiments were performed for characterization of thermal stability of studied materials. Obtained magnitudes of activation energy corresponds to the degradation of natural rubber.

Table 1. Calculated activation energy values of thermal decomposition of studied rubber materials according to Kissinger and OFW methods.

OFW	E_a *(kJ/mol)*
α = 5%	233.5
α = 10%	194.4
α = 20%	188.6
α = 30%	160.3
Kissinger	161.9

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Fig. 3. *Bi-axial tensile testing results: (a) Thickness reduction vs. loading. (b) Minor strain vs. loading.*