INVESTIGATION OF THE DEFORMATION OF A RUBBERY NETWORK POLYMER (SKN-40) IN VARIOUS TYPES OF STATES OF STRESS

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From the experimental data on equilibrium uniaxial and nonsymmetrical and symmetrical biaxial tension and pure and mixed shear it follows that the deformation behavior of SKN-40 crosslinked butadiene-nitrile copolymer is more accurately described by the Bartenev-Khazanovich high-elastic potential. The potential of the classical statistical theory of high elasticity of network polymers does not describe different types of states of stress with the same value of the material constant.

In order to develop methods of designing rubber parts it is necessary to know the high-elastic potential that most accurately describes the deformation behavior of rubbery materials in different types of states of stress. At present the high-elastic potential of the classical theory of high elasticity of polymer networks [1] and the Mooney equation with a correction term (two-parameter equation) are those most commonly employed.

In [2] various one-parameter equations (the equation of the classical statistical theory of high elasticity [1], the Bartenev-Khazanovich equation [2], and others [3]) were compared with the experimental uniaxial tension data of [4], the data on uniaxial and symmetrical biaxial tension of [5], and the data on uniaxial tension and pure and mixed shear of [6], and it was shown that the one-parameter Bartenev-Khazanovich equation describes the deformation behavior of rubber network polymers better than other one-parameter expressions containing a single material constant. Also in [2] certain two-parameter expressions containing two material constants (Mooney-Rivlin [7, 8], Gent and Thomas [9, 10], Priss [11], and Bartenev-Khazanovich [2]) were compared with the experimental data of Rivlin and Saunders [6] and Treloar [12] on symmetrical biaxial tension and it was shown that up to 200-300% extension the Bartenev-Khazanovich two-parameter equation is superior.

In [13] the experimental data of various authors on unfilled rubbers in uniaxial tension were compared with the above-mentioned one-parameter equations, the Mooney-Rivlin [7, 8], Martin, Roth, and Stiehler [14], and Bartenev-Khazanovich [2] two-parameter equations, and the Zahorski three-parameter equation [15]. It was shown that of the one-parameter equations that satisfactorily describe the strains up to 100% extension the Bartenev-Khazanovich equation is the most suitable. At the same time, all the two-parameter equations give a good description of the deformation behavior of unfilled rubbers up to failure.

In our recently published papers [16, 17] it was shown that the deformation behavior of unfilled rubbers in uniaxial and nonsymmetrical biaxial tension is best described by the Bartenev-Khazanovich one-parameter equation and the equation of the classical theory of rubber elasticity.

Accordingly, we selected two forms of the high-elastic potential with one-material constant for further more detailed investigation. Firstly, the equation of the classical statistical theory of rubber elasticity

Fig. 1. Experimental data in generalized coordinates for the network polymer SKN-40 in uniaxial tension: 1) according to Eq. (4); 2) according to Eq. (5).

Fig. 2. Experimental data for biaxial nonsymmetrical tension: 1) for the stress $\sigma_1$ and $D(\lambda) = \lambda_1^2 - \lambda_2^2$; 2) $\sigma_2$ and $D(\lambda) = \lambda_2^2 - \lambda_3^2$; 3) $\sigma_4$ and $D(\lambda) = \lambda_1 - \lambda_3$; 4) $\sigma_2$ and $D(\lambda) = \lambda_2 - \lambda_3$.

$$W = \frac{G}{2} (\lambda_1^2 + \lambda_2^2 + \lambda_3^2 - 3),$$

(1)

secondly, the Bartenev-Kazhanovich one-parameter equation

$$W = A (\lambda_1 + \lambda_2 + \lambda_3 - 3),$$

(2)

where $W$ is the high-elastic potential; $\lambda_i$ are the relative extensions along the three strain axes ($i = 1, 2, 3$); $G$ and $A$ are material constants that do not depend on the nature of the state of stress. In the corresponding theories it is shown that the material constants depend in a certain manner on the structure of the network polymer.

These equations were selected because they are one-parameter and, consequently, the calculations are less complicated than when the numerous multi-parameter equations containing several constants [7-11, 14, 15, 18-23] are employed. The high-elastic potential makes it possible to find the difference of the principal stresses for any variant of the state of stress from the expressions

$$\sigma_i - \sigma_j = \lambda_i \frac{\partial W}{\partial \lambda_i} - \lambda_j \frac{\partial W}{\partial \lambda_j},$$

(3)

where $i, j = 1, 2, 3$ and $\sigma_i$ and $\sigma_j$ are the true stresses.

Below we present the experimental data on the deformation characteristics of an unfilled nitrile rubber vulcanizate in uniaxial and symmetrical and nonsymmetrical biaxial tension and pure and mixed shear. These data are then employed in an analysis of the chosen equations. The investigated vulcanizate had the following composition: SKN-40 rubber 100 pts. by wt., magnesium oxide 5 pts. by wt., stearin 1 pt. by wt., sulfur 1.5 pts. by wt., Captax 0.8 pt. by wt. Vulcanization was carried out under optimal conditions at 151°C and a vulcanization time of 40 min. Specimens of the "cross" type were tested in the equilibrium deformation regime at 20°C in the apparatus previously described in [16, 17]. Since experiments were performed on specimens made at different times, great attention was given to the strict constancy of all the parameters: vulcanization temperature, time and pressure, weight of vulcanizate, etc. All the specimens were prepared from the same batch. Thus they all had quite similar material characteristics. For example, the shear modulus $G$ in Eq. (1) varied by less than 2% from specimen to specimen.