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CHANGE IN VOLUME OF REAL ELASTOMERS UNDER UNIAXIAL TENSION

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The characteristic of transverse compression ν, generalizing Poisson's ratio to the case of moderately large elongations, has been introduced for elastomers. It has been found that for 10 rubbers used in the footwear industry ν is constant up to a breaking strain of the order of 150%.

The relative change in the volume of the rubber is calculated from the formula [1]

$$\theta = (dV - dV^0)/dV^0 = \lambda_1\lambda_2\lambda_3 - 1$$

(λ_i are the principal multiplicities of the elongations). Under uniaxial tension

$$\lambda_1 = \lambda > 1,\ \lambda_2 = \lambda_3 = \lambda^{-1/2}\sqrt{1+\theta}.$$

By S^0 and S we denote the cross-sectional areas of the sample before and after deformation, related by

$$S^0/S = 1/\lambda_2\lambda_3 = \lambda/(1+\theta). \tag{1}$$

We introduce the characteristic ν as follows

$$S^0/S = 1 + (\lambda - 1)2\nu. \tag{2}$$

From (1) and (2) we have

$$\theta = (1 - 2\nu)(\lambda - 1)/[1 + (\lambda - 1)2\nu]. \tag{3}$$

For small strains

$$\lambda - 1 = e_1,\ e_2 = e_3 = -\bar{\nu}e_1,$$

where e_i are the principal relative elongations; and $\bar{\nu}$ is Poisson's ratio. Since the relative elongations are small (e_1, $e_2 \ll 1$) we have

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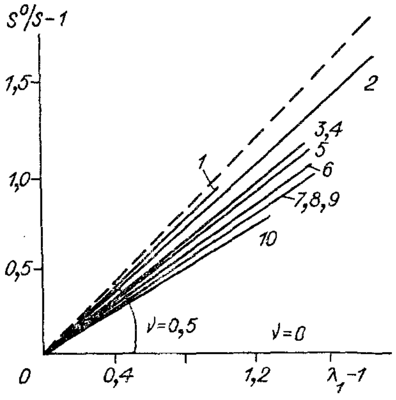

Fig. 1

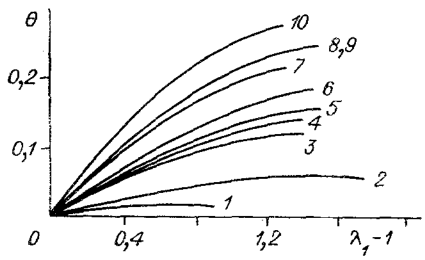

Fig. 2

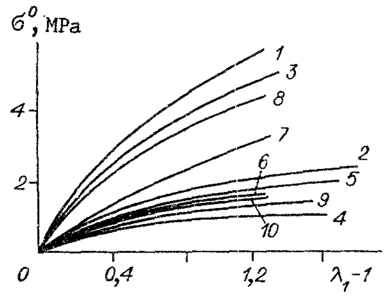

Fig. 3

TABLE 1

No.	Rubber	Composition of rubber (mass fraction of components, %)	ν	Initial modulus E_{in}, MPa
1	Vida B (black)	SKMS-30 RP (25) Reclaimed rubber (20) Carbon PM-75 (36) Sulfur (1,5)	0,49	10,0
2	Mark VSh-6 (white)	BS-45 AKN (30) SKMS-30 RP (5) SKD (10) Filler (20,9) Sulfur (1,7)	0,46	3,581
3	Mark B-2	SKMS-30 RP (18,1) Reclaimed rubber (33,3) Carbon PM-75 (32,0) Sulfur (1,3)	0,39	7,136
4	Porokrep	SKMS-30 ARKPN (20) BS-45 AKN (30) BS-100 carbon black (14.8) Sulfur (2,0)	0,39	1,509
5	Mark VSh-2 (brown)	SKMS-30 RP (23,8) Reclaimed rubber (14,3) Filler (42,6) Sulfur (1,5)	0,38	2,716
6	Mark VSh-2 (red)	BS-45 AKN (30) SKD (10) Reclaimed rubber (15) Filler (20,9) Sulfur (1,7)	0,36	2,470
7	"Malysh" (blue)	BS-45 AKN (35) SKI-3 (15) Filler (32,1) Sulfur (1,6)	0,34	4,693
8	Vida ASh (black)	SKMS-30 RP (25) Reclaimed rubber (20) Filler (36) Sulfur (1,5)	0,33	7,107
9	Mark V-1 (black)	BS-45 AKN (35) SKMS-30 RP (7) SKD (8) Reclaimed rubber (15) Filler (15) Sulfur (1,75)	0,33	2,033
10	"Pod probku" (white)	BS-45 AKN (45) Filler (32) Sulfur (1,5)	0,30	1,509

$$\frac{S^0}{S} = \frac{1}{(1+e_2)(1+e_3)} = \frac{1}{(1-\nu e_1)^2} \simeq 1 + 2\bar{\nu} e_1.$$

Comparison of this equation with (2) gives $\nu = \bar{\nu}$, i.e., at small strains ν goes over into Poisson's ratio. At large strains, generally speaking, $\nu = \nu(\lambda)$.

Samples in the form of a two-sided paddle were prepared from the 10 types of rubber used in the footwear industry (see Table 1) and were then stretched without necking on an RT 250-2M machine. The experiments (Fig. 1) showed that ν is constant for all types of rubber considered. The dashed line corresponds to the incompressible material ($\nu = 0.5$). Figure 2 shows $\theta = \theta(\lambda_1)$ and Fig. 3, the dependence of the relative stress on the multiplicity of elongation $\sigma^0 = \sigma^0(\lambda_1)$. The relative stress was calculated at the ratio of the force to the initial (before deformation) cross-sectional area of the sample.

The main result follows from Fig. 1: up to breaking strains of the order of 150%, at least for the filled rubbers under consideration, ν is a generalization of Poisson's ratio for moderately large strains. A notable deviation of the generalized Poisson's ratio from $\nu = 0.5$ is evidence of the considerable porosity of the given materials.

The expression (3) for the relative change in volume can be recast in the form

$$\theta = \theta^\infty - (1-2\nu)/\{2\nu[1 + 2\nu(\lambda - 1)]\},$$

where $\theta^\infty = (1 - 2\nu)/2\nu$ is the limiting value [as $(\lambda - 1) \to \infty$] of the relative change in volume.

In conclusion we note the following. 1. The coefficient ν can serve as a measure of the decrease in the cross-sectional area (under elongation up to 150%) for the considered 10 types of rubber used in the footwear industry. 2. The main change in volume occurs under moderate strains. The errors often found in the literature in the model of an incompressible material when moderate tensile strains of elastomers are described evidently are associated with this [3].

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