INFLUENCE OF HARDNESS ON MECHANICAL PROPERTIES OF ELASTOMERS

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Abstract

In this paper, elastomers with different hardness factors were examined to evaluate the influence of the hardness on their mechanical properties. The following hardness numbers, measured in Shore A hardness scale, were investigated: 40; 60; 70 and 90°. Basic mechanical tests i.e. axial tension and axial compression have been performed in order to calculate elastic properties and stress values corresponding to the fixed strains: $\varepsilon = 0.2$; 0.3 and 0.5. The $\sigma(\varepsilon)$ dependences from the tension and compression tests are nonlinear and have different shapes. The tension plot can be described by a convex parabola, while the compression curve can be approximated by a concave one. Dynamic load tests with loading frequencies 0.01; 0.1; 1.0 and 3,0Hz were performed in order to determine the hysteresis loop and to obtain force and displacement dependences in time. From those results the following factors were calculated: relative damping coefficient and mechanical loss angle, as well as their dependence on load frequencies. The influence of hardness on both in-phase and out-of-phase components of normal modulus were investigated. The sensitivity of the examined elastomers to the loading rate was also investigated.

***Keywords**: experimental research, elastomers, mechanical properties, relative damping coefficient, mechanical loss angle*

1. Introduction

Elastomers, especially these with Shore Hardness 40°, exhibit high elastic properties and are able to withstand a tension test with strains up to 200%. In handbook [1] authors suggest that despite their aliphatic structure, elastomers are homogeneous and isotropic materials (the highest chain dimension is 1μm), which means that the Poisson ratio can be approximately assumed equal to 0.5. Basing on own research, this factor changes slightly with the hardness change.

In paper [1] were presented basic but very extensive studies of a rubber considered as a type of elastomer. This work describes molecular structure, physical and mechanical properties of rubbers and experimental methods in different dynamic and static load conditions. A dynamic dumping is reviewed in [2], while [3] is concerned with experimental investigations of rubber mechanical properties. In [4] a wide range of data considering the rubber can be found.

The following norms were applied in the investigations: PN-ISO 37 Rubber, vulcanized or thermoplastic – Determination of tensile stress-strain properties; PN-54/C-04253 Rubber – Determination of compression strain; PN-80/C-04290 Rubber – Determination of compression set; PN-92/C-04251 Rubber vulcanized or thermoplastics – Determination of tension set at normal and high temperatures; PN-87/C-04289 Rubber vulcanized – Determination of relative damping in compression stress; PN-78/C-1604 Rubber – Terminology – Dynamic properties; PN-61/C-04218 Rubber – Flexing resistance test; PN-78/C-04338 Rubber – Determination of resistance to multiple extension.

The main objective of this research is to evaluate the influence of the elastomers' hardness on their mechanical properties, i.e. complex normal modulus, tensile and compression strength, as well as the influence of load frequency on damping properties.

2. Experimental techniques

The study was concerned with elastomers with four different Shore hardnesses 40, 60, 70, 90°. The rubbers were made from: nitrile rubber, stearin, zinc white, anti-ageing formula, carbon black, softener, sulphur and accelerating agent.

The shapes of the examined specimens were different from the ones recommended by the norms, because of the high speed camera, which was used to measure strains. The shapes of the specimens for tension, compression and changing load tests are presented in Fig. 1.

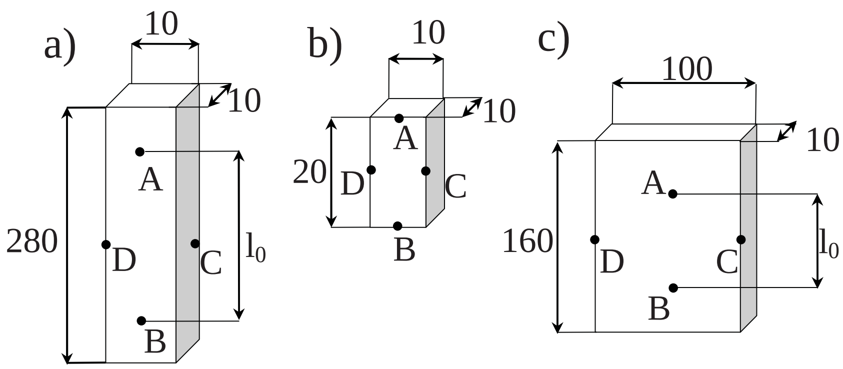

Fig. 1. The shapes of the examined specimens: a) – tension test, b) – compressions test, c) – symmetric changing load test

The investigations were made on the standard tension machine Instron 8802, at temperature 20°C and humidity 60%. In tension and compression tests (the specimens presented in Fig. 1 a) and b)) a force gauge with range up to 1kN was placed between both machine holders, in order to increase the accuracy of measurements – Fig. 2. The static tests were performed with load ratio 200 mm/min. The strain values in stress-strains dependences were obtained in two ways, i.e. from the displacement data recorded by the camera between points A-B and C-D (Fig. 1), and calculated from the data recorded automatically by the tension machine.

Engineering stresses and actual stresses were obtained from static tension and static compression tests using the following formulas:

$$\sigma_u = \frac{P}{A_0}, \tag{1}$$

$$\sigma_{rz} = \frac{P}{A_x}, \tag{2}$$

where:
P - tension or compression force,
A_0 - initial cross-section area of a specimen,
A_x - actual cross-section area for a given specimen shortening. A_x was obtained using A_x and Poisson ratio data.

Poisson ratio was determined on the grounds of the PN-78/C-01604 norm, using the following equation:

$$\nu = \frac{1}{2}\left[1 - \frac{1}{V}\frac{\partial V}{\partial \varepsilon}\right], \tag{3}$$

where:
V - volume of a specimen in m^3,
$\varepsilon = \frac{\Delta l}{l_0}$ - strain.

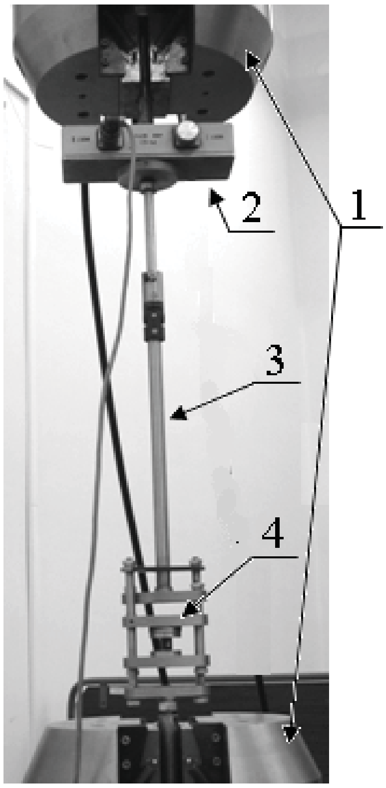

Fig. 2. Picture of the testing machi ne with the additional force indicator shown: 1 – test machine heads ; 2 – force gauge 1kN; 3 – reverse; 4 – a compressed specimen

Elastomers are considered as isotropic materials so that the formula below can be applied to evaluate the shear modulus:

$$G = \frac{E_1}{2(1+\nu)}. \tag{4}$$

The in phase elastic modulus E_1 was determined from periodically changing load tests and it corresponds to the elastic Young modulus. The loss factor (loss tangent) (tgφ) and relative damping coefficient (energy dissipation factor) (ψ) were obtained from changing load tests. The loss factor is equal to the tangent of the mechanical loss angle (tgφ). The method used to evaluate the angle φ is shown in Fig. 3.

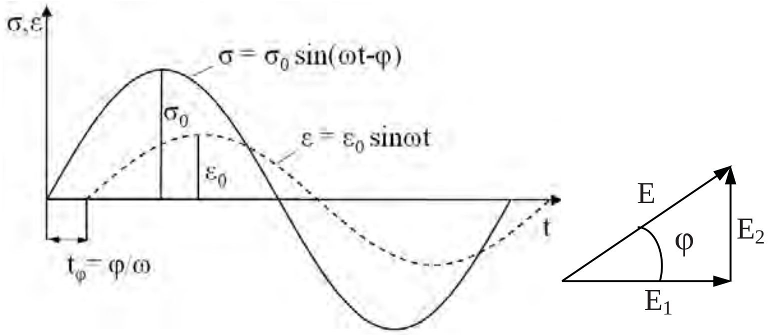

Fig. 3. Determining of mechanical loss angle

where:

σ_0, ε_0 - stress amplitude and strain amplitude,

φ –mechanical loss angle,

$\omega = 2\pi f$,

f - frequency,

t_φ - time of the phase loss.

The complex normal modulus can be decomposed into two components E_1 and E_2, where:

$E_1 = \frac{\sigma_0}{\varepsilon_0}\cos\varphi$ - normal modulus in phase (elastic modulus),

$E_2 = \frac{\sigma_0}{\varepsilon_0}\sin\varphi$ - out of phase component of the normal modulus (dissipation modulus).

The relative damping coefficient is calculated from the formula:

$$\psi = \frac{w_2}{w_1} = \frac{L_{ob} - L_{od}}{L_{ob}}, \tag{5}$$

where:

w_2 - dissipation energy (the energy transformed into heat during one load cycle),

w_1 - energy of elastic deformation.

Energies w_2 and w_1 are calculated on the basis of the recorded hysteresis loop: L_{ob} – loading work and L_{od} – unloading work are obtained by integration of the corresponding areas (Fig. 4):

$$L_{obc} = \int_0^l P_{obc}\,dl, \tag{6}$$

$$L_{odc} = \int_0^l P_{odc}\,dl. \tag{7}$$

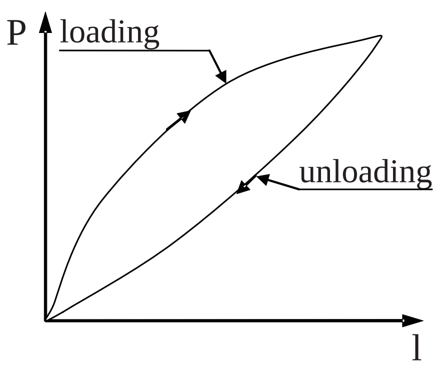

Fig. 4. The hysteresis loop for symmetric load cycle adjusted for Lobc and Lodc calculations

The relative damping coefficient and mechanical loss angle are connected by the relationship:

$$\psi = 2\pi \cdot tg\varphi \,. \tag{8}$$

3. Results

The mechanical properties of elastomers with different hardness are presented in Tab. 1 and in Fig. 5-13. The static tension and compression tests were made in order to evaluate the stress-strain dependence and elastic properties. The changing load tests were performed to obtain damping properties of the examined elastomers in a shape of relative damping coefficient and loss tangent.

Figure 5 and 6 present engineering stress versus strain graphs for the examined hardness values in tension and compression tests, respectively. Fig. 7 presents stress in time and strain in time graphs for load frequency 0.1Hz, amplitude 30% and hardness 60° ShA and the phase angle between stress and strain can be observed. This is one of the sixteen examined variants: four different hardnesses (40, 60, 70, 90°) and four different load frequencies (0.001, 0.1 1.0, 3.0 Hz). Fig. 8 presents the hysteresis loop for the same test variant, to demonstrate the mechanical energy loss.

Pictures from the tests of: a) tension, b) compression and c) changing load are presented in Fig. 9. No buckling specimens occurred.

Figure 11 and 12 present selected mechanical properties from Tab. 1, as a function of the elastomer hardness. On the first graph the following data are presented: tensile strength, normal modulus in phase and shear modulus. The tensile strength is approximated by a second degree polynomial, while the others are approximated by linear functions. The second figure presents the out of phase modulus curve and the data points are approximated by a second degree polynomial. The presented mechanical properties are increasing with the hardness increase.

Because of the test machine capabilities (limited piston move), the specimens were extended to the strain equal to 250% (Tab. 1).

Tab. 1. Mechanical properties determined in the research

Nr	Mechanical properties	Hardness °ShA				Frequency Hz
		40	60	70	90	
1	Tension strength (R_r) [MPa]	1.95 (ε=2.5)	7.8 (ε=2.5)	9.0 (ε=2.5)	12.7	-
2	Compression strength (R_c) [MPa]	-	-	12.8	14.6	-
3	Normal modulus in phase (E_1) [MPa]	21.4	28.5	36.6	73.5	-
4	Out of phase component (E_2) [MPa]	0.783	1.18	1.92	3.7	-
5	Shear modulus (G) [MPa]	7.13	9.5	12.2	24.5	-
6	Poisson's ratio (ν)	0.493	0.497	0.498	0.498	-
7	Relative damping coefficient (ψ)	0.24	0.26	0.34	0.35	0.01
		0.23	0.26	0.33	0.316	0.1
		0.206	0.142	0.32	0.302	1.0
		0.2	0.108	0.28	0.292	3.0
8	Loss factor (tg_φ)	0.0382	0.0414	0.054	0.056	0.01
		0.0366	0.0414	0.0525	0.0503	0.1
		0.0328	0.0226	0.0509	0.048	1.0
		0.0318	0.0172	0.0446	0.046	3.0

The dependence of strain ratio on the engineering stress was examined basing on the first quarters of the ε(t) and P(t) plots. Four load frequencies (0.001, 0.1 1.0, 3.0 Hz) and four hardness values (40; 60; 70; 90° ShA) were tested. For strain 30%, the displacement of the machine piston was equal to 6 mm, which resulted from the set load frequencies. Fig. 13 presents the resulting plots.

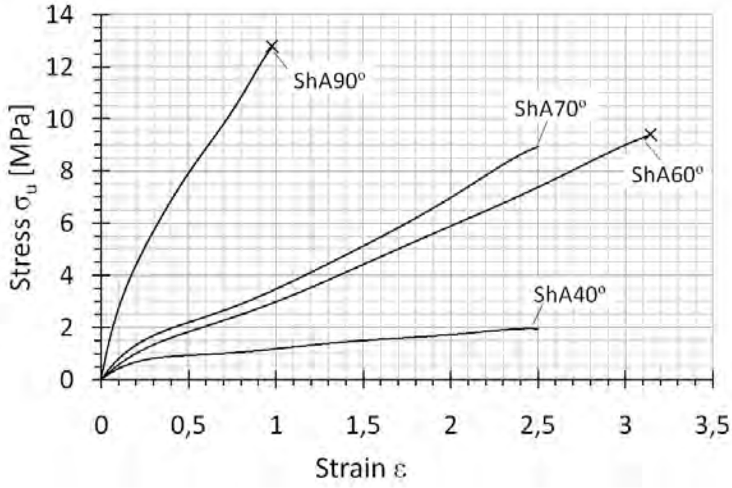

Fig. 5. The dependence engineering stress – strain under tension load for the examined elastomers

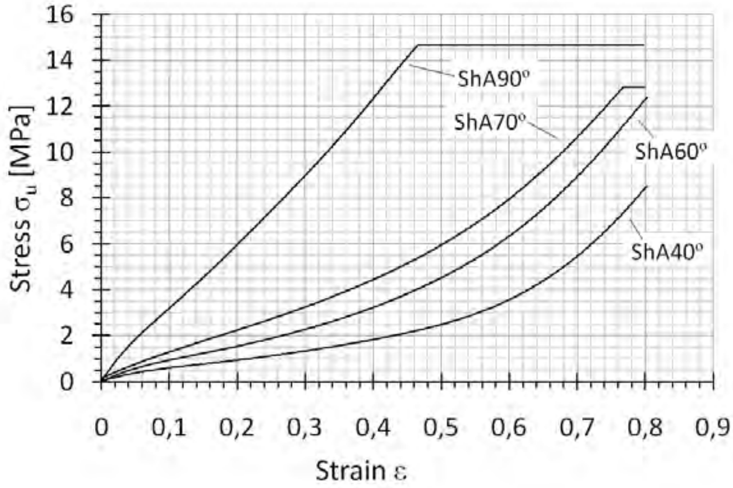

Fig. 6. The dependence engineering stress – strain under compression load for the examined elastomers

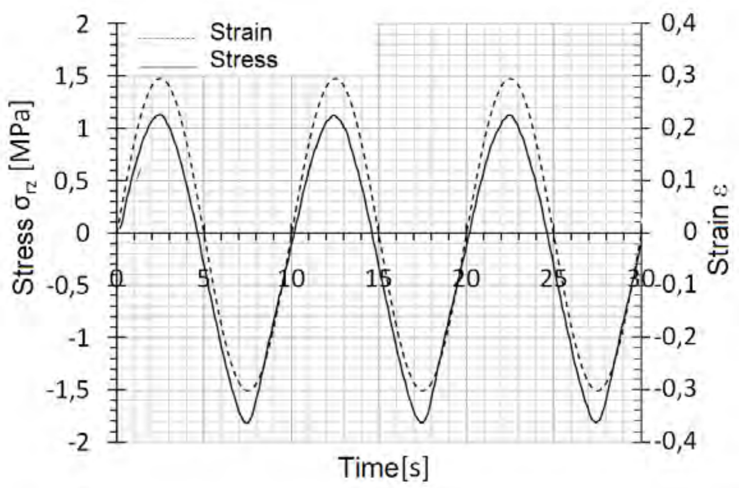

Fig. 7. The time function of actual stress and strain for frequency 0,1Hz, amplitude 30% and hardness 60º ShA

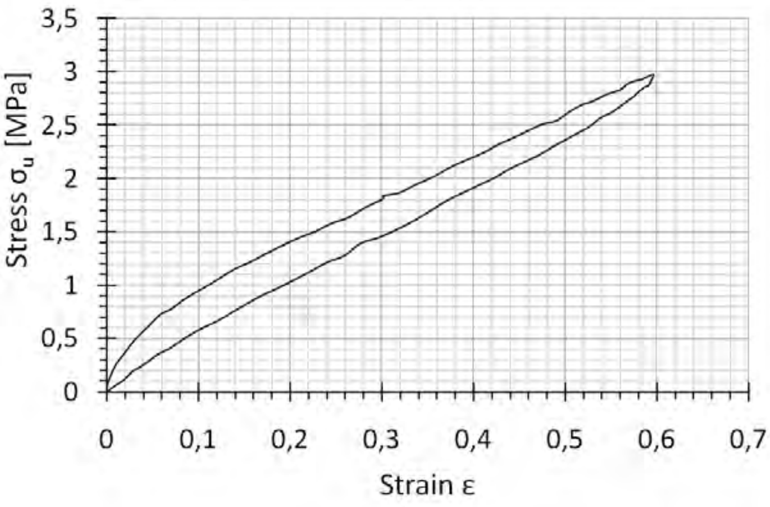

Fig. 8. The hysteresis loop for the same data as in Fig. 7

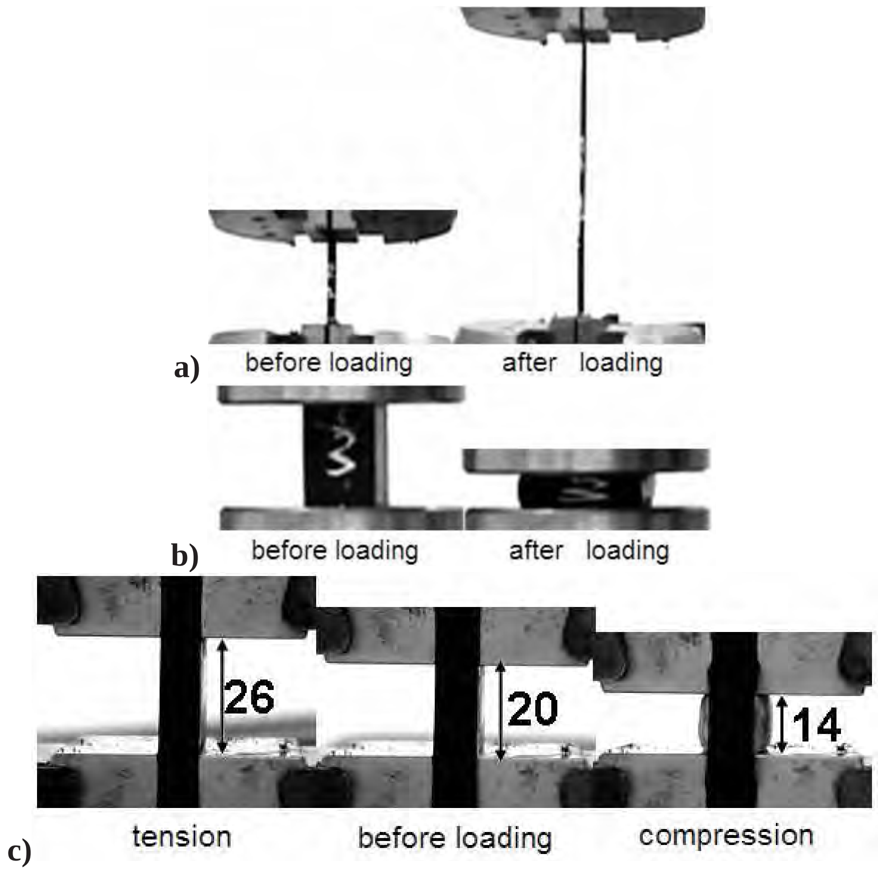

Fig. 9. Pictures of the specimens during tests: a) – tension, b) – compression, c) – changing load

4. Summary

On the basis of the presented experimental results (Tab. 1), the following conclusions can be drawn:

1. Both tensile and compression strength increase with hardness.
2. The shear modulus (G) and both in phase (E_2) and out of phase (E_2) components of the complex modulus also increase (Fig. 11 and 12).
3. The Poisson ratio depends insignificantly on the elastomer hardness. For simple or preliminary calculations value ν=0.5 can be assumed.

4. With load frequency increase in changing load tests, both relative damping coefficient and loss factor decrease.
5. In the load ratio range changing from 15mm/min. to 1500 mm/min., and with strains set equal to ε=30%, the stress is not dependent on the load ratio.

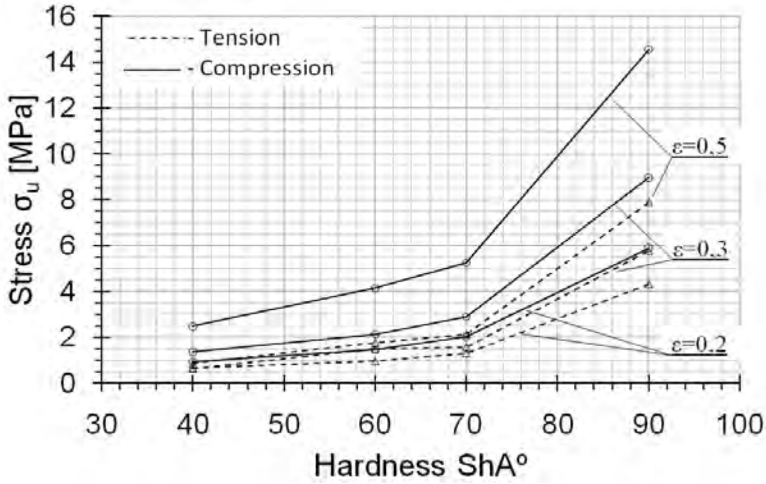

Fig. 10. The influence of elastomers' hardness on stress for selected strain values

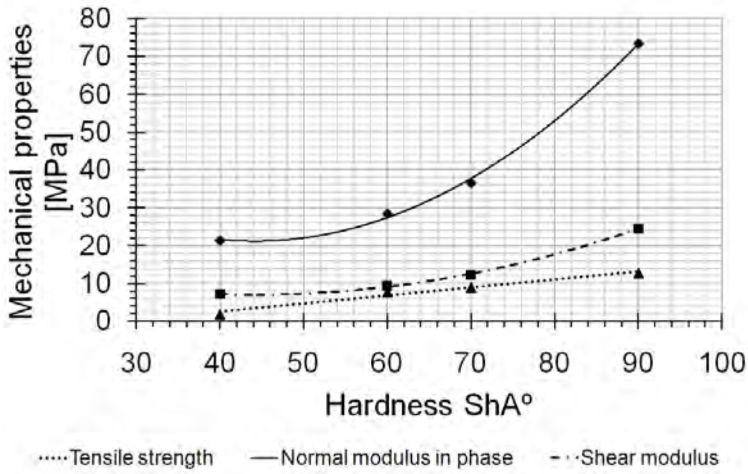

Fig. 11. The influence of hardness on elastomer mechanical properties (Tab. 1)

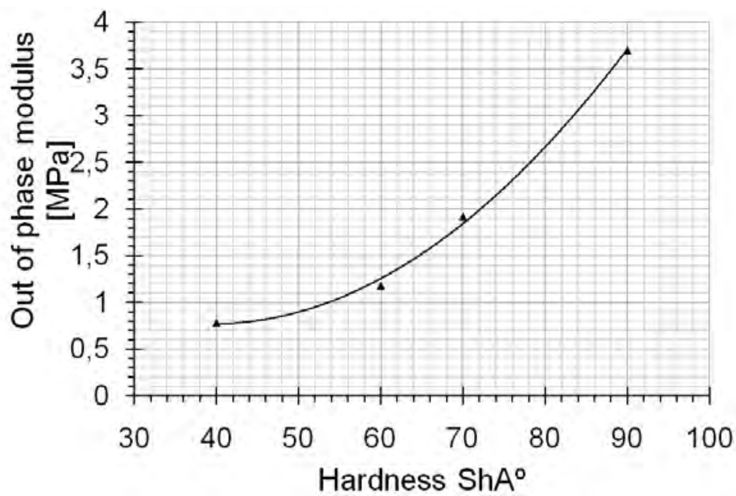

Fig. 12. The influence of hardness on the out of phase component of normal modulus (Tab. 1)

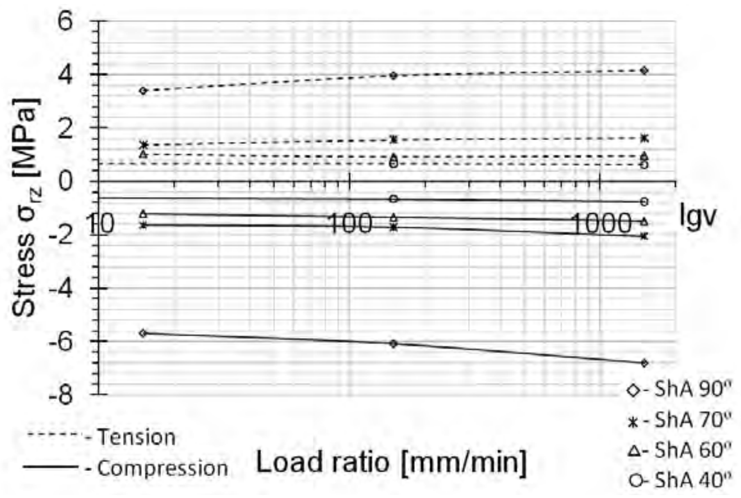

Fig. 13. The dependence of actual stress on load ratio for the examined hardness factors

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