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COMPRESSION MODULUS OF ELASTOMERS

BY

DANIELA OANEA FEDIUC[1,*], MIHAI BUDESCU[1], VLAD FEDIUC[2] and VASILE-MIRCEA VENGHIAC[1]

"Gheorghe Asachi" Technical University of Iaşi
[1]Department of Structural Mechanics
[2]Department of Transportation Infrastructure and Foundations

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Abstract. In civil engineering elastomers are mainly used in bridge bearings and base isolation bearings for structures located in seismic zones.

This paper presents general characteristics of elastomers, measurements obtained with a Zwick hardness tester, several relationships to determine the compression modulus of an elastomer layer and experimental determination of compression modulus on elastomer specimens with different compositions: CR (chloroprene/neoprene rubber); NR (natural rubber); NR/BR (natural rubber/butadiene rubber); NR/BR/SBR+PA/PE Fibres (natural rubber/butadiene rubber/styrene butadiene rubber and polyamide/polyethylene fibres). The compression test of elastomer specimens was achieved with a Controlled Electro Mechanism Universal Testing Machine WDW.

The aim of this study was to investigate and define the relationship between compression and shear modulus, hardness and shape factor. The results show reasonable agreement between theoretical and experimental values.

Key words: elastomer; Shore hardness; compression modulus; shape factor.

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* Corresponding author: *e-mail:* oaneadaniela@yahoo.com

1. Introduction

The elastomers are formed from a blend of a base polymer and other chemical substances. This mixture of components is designed to obtain the characteristics required to optimize the performance of products. In the composition of elastomers there may be added reinforcing agents, curing or vulcanization agents, activators, plasticizers, accelerators, anti-oxidants or anti-radiation additives. There can be made a lot of combinations; ISO 1629 identifies approximately 25 types of elastomers.

In practice, the performance level of elastomers is estimated by hardness, elastic moduli, resistance to various stresses, abrasion, oils, aging, etc.

Elastomers are materials that do not respect the Hooke's law, the deformation is not directly proportional to the applied load. Elastomers have properties similar to viscoelastic materials. Compared to conventional materials used in technical engineering, the deformation mechanism of elastomers varies greatly. Poisson's ratio of elastomers is 0.5, so it behaves like a liquid and the relationship between the elastic moduli is $E = 3G$.

Elastomers have many characteristics: energy absorption, flexibility, high elasticity, long service life, ability to protect against moisture, pressure and heat, non-toxic properties, variable stiffness, good dielectric properties. Elastomers can be glued on different synthetic materials, have good qualities of bending at low temperatures, are cheap and can be obtained in a wide range of hardness values.

Elastomers are damaged when exposed to the oils, fuels, solvents, hydraulic fluids and have low resistance to petroleum products and organic chemicals. If special additives are not used, elastomers present a low resistance to sunlight, oxygen, ozone and high temperature.

2. Elastomers Hardness

Hardness is the property of a material that expresses the degree of resistance to scratching, puncturing or deformation. The hardness is measured in degrees, either Shore Hardness, International Rubber Hardness (IRHD) or British Standard (BS), (Aiken *et al.*, 1989).

In order to determine the hardness of elastomers the Shore test, named after Albert F. Shore, is used. Shore is the one who suggested this test in 1907. The test is made with a measuring device called *durometer* and the Shore hardness is a number comprised between 0 and 100 defined in many standards such as ASTM D 2240:2003, BS 903:1997, ISO 7619:2004 (Giannakopoulos *et al.*, 2009).

To determine the hardness with the Zwick/Roell 3114..17 hardness tester (Fig. 1), the standard specimen should have a minimum thickness of 6 mm and it should not be subjected to mechanical stress.

Fig. 1 – The Shore hardness test.

According SR ISO 7619-1:2011, the measurement of an elastomer hardness depends on several factors namely: the elastic modulus and the viscoelastic properties of the elastomer, the thickness of the test sample, the geometry of the indenter, the pressure exerted, the pressure increase rate and the interval at which the hardness is recorded (SR ISO 7619-1:2011).

The Shore hardness test was carried out on four elastomer specimens with different compositions:

a) CR – chloroprene/neoprene rubber;

b) NR – natural rubber;

c) NR/BR – natural rubber/butadiene rubber;

d) NR/BR/SBR+PA/PE fibres – natural rubber/butadiene rubber/styrene butadiene rubber and polyamide/polyethylene fibres.

The materials were provided by S.C. FREYROM S.A., which is the manufacturer of bearings for seismic base isolation and bearings for bridges. The specimens have a diameter of 28.5 mm and a thickness of 13 mm (Fig. 2).

Fig. 2 – The elastomer specimens.

The test result for hardness was the arithmetic mean of five measurements at different positions on the sample (SR ISO 7619-1:2011).

In Table 1 the hardness values, in Shore A degrees for the four elastomer specimens, are presented.

Table 1
Values of Shore A Hardness

CR	NR	NR/BR	NR/BR/SBR +PA/PE fibres
64	65	63	65

3. Compression Modulus

Over the years, several relationships have been proposed to determine the compression modulus of an elastomer layer which has both sides provided with plates (the addition of metal plates prevent the deformations at the contact surface).

The first relationship was proposed by Rocard in 1937 for very small and very large values of shape factor (Aiken *et al.*, 1989)

$$E_{c1} = 3G\left(\frac{1+k_1S^2}{1+k_2S^2}+2S^2\right), \tag{1}$$

where: G is the shear modulus, k_1 = 4.8; k_2 = 4 – their values depend on the variation of shape factor; S – the shape factor.

The shape factor for an elastomer layer was first defined by Keys in 1937 (Aiken *et al.*, 1989)

$$S = \frac{\text{loaded area}}{\text{force} - \text{free area}}. \tag{2}$$

The shape factor for a circular layer of radius r and thickness t is

$$S = \frac{\pi r^2}{2\pi rh} = \frac{r}{2h}. \tag{3}$$

The second relationship was proposed by Gent and Lindley in 1959 (Aiken *et al.*, 1989; Gent, 2001; Kelly, 2001),

$$E_{c2} = E_0(1+2kS^2), \tag{4}$$

where: E_0 is Young's modulus, E_0 = 3G for unfilled, low-damping elastomers and $E_0 = 4G$ E_0 = 4G for high-damping elastomers with carbon black filler; k – the material modifying factor, determined experimentally.

The elastic moduli and the material modifying factor of elastomers vary depending on the material hardness (Fig. 3), (Bauman, 2008).

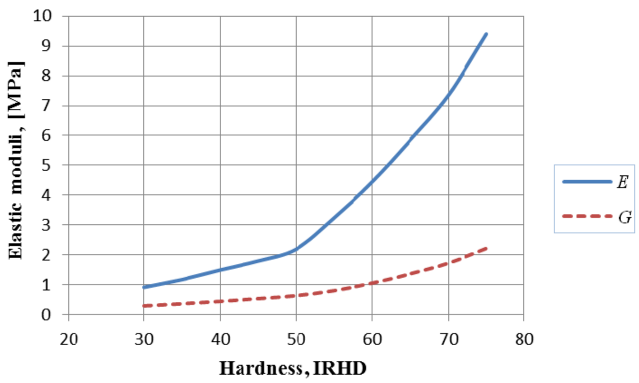

Fig. 3 – The variation of elastic moduli *vs*. the elastomer hardness.

The values of Young's modulus depending on the two scales of hardness, namely Shore A and IRHD, are illustrated in Fig. 4 (Gent, 2001).

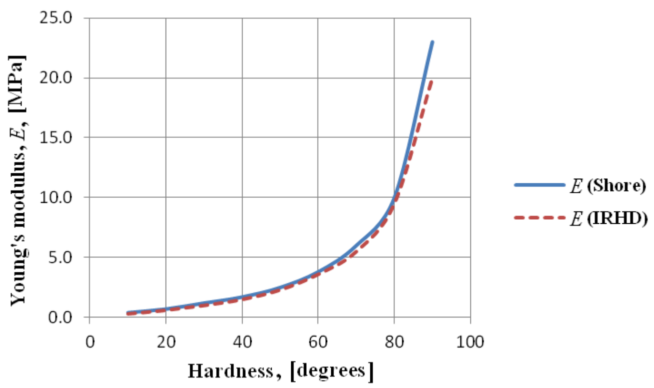

Fig. 4 – The variation of Young's modulus *vs*. the elastomer hardness degrees (Shore and IRHD).

The third relationship to determine the compression modulus is described by Derham for values of the shape factor $S > 3$ (Aiken *et al.*, 1989)

$$E_{c3} = 5.6GS^2 . \quad (5)$$

The fourth relationship belongs to Derham who studied eq. (1) of Rocard and found different values for coefficients, namely $k_1 = 9$, $k_2 = 4$, then he modified the eq. based on hardness (Aiken *et al.*, 1989)

$$E_{c4} = \frac{H^{1.9}}{6,700}\left(\frac{1+9S^2}{1+4S^2} + 2S^2\right) \text{ ksi}, \tag{6}$$

where: H is the elastomer hardness; ksi – the kilopound per square inch, 1 ksi = = 10^3 psi ≈ 6.89475 MPa.

The fifth relationship to determine the compression modulus of an elastomer layer with circular section is proposed by Kelly, for shape factor $S > 5$ (Kelly *et al.*, 2011)

$$E_{c5} = 6GS^2. \tag{7}$$

To establish what relationship can be used to determine the compression modulus of elastomer specimens, the shape factor was calculated with eq. (2) resulting S = 0.55. Thus the moduli were calculated using the following eqs.: eq. (1) – Rocard, eq. (4) – Gent and Lindley and eq. (6) – Derham, in view to observe the differences between the relationships. The theoretical results are shown in Table 2 together with the experimental values.

4. Experimental Determination of Compression Modulus

According to the standard of elastomers compression test, ASTM D 395-03, the standard dimensions of a specimen are: thickness – 12.5 ± 0.5 mm and diameter – 29.0 ± 0.5 mm.

The compression test of elastomer specimens was achieved with a Controlled Electro Mechanism Universal Testing Machine WDW. The compression load was progressively applied with a speed of 0.05 kN/s and the maximum value was of 0.2 kN.

The Controlled Electro Mechanism Universal Testing Machine allows automatic recording of the force and displacement using the program WinWdw (Fig. 5).

The theoretical and experimental results of secant modulus at compression for the four elastomer specimens are shown in the Table 2.

Table 2
Secant Compression Modulus Values

	E_{c1}, [MPa]	E_{c2}, [MPa]	E_{c4}, [MPa]	E_{cs}, [MPa]
CR	6.82	7.40	6.35	7.55
NR	7.03	7.75	6.54	7.72
NR/BR	6.60	7.04	6.16	6.53
NR/BR/SBR+ PA/PE Fibres	7.03	7.75	6.54	7.72

The results obtained using different expressions for compression moduli E_{c1}, E_{c2}, E_{c4} indicate approximately equal values to each other and to the secant modulus values E_{cs} (experimentally determined).

Fig. 5 – The WDW- Computer Controlled Electro Mechanism Universal Testing Machine.

Ten cycles of loading–unloading were performed to establish when the stabilization of the hysteresis loop occurs (Figs. 6,...,9).

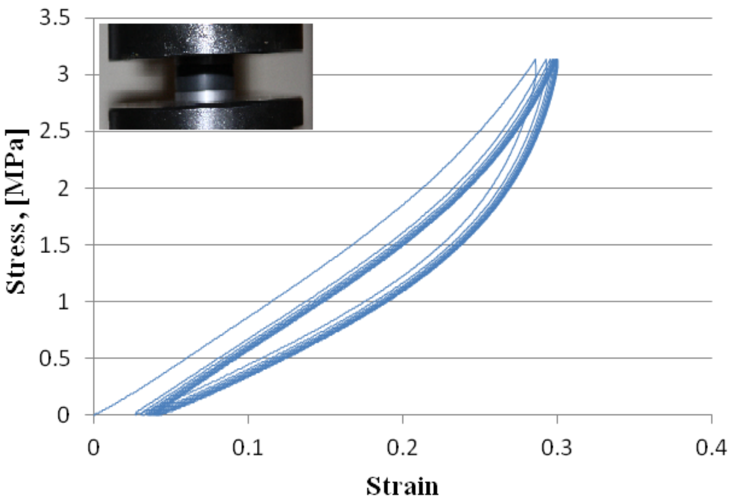

Fig. 6 – Stress–strain curves of CR specimen.

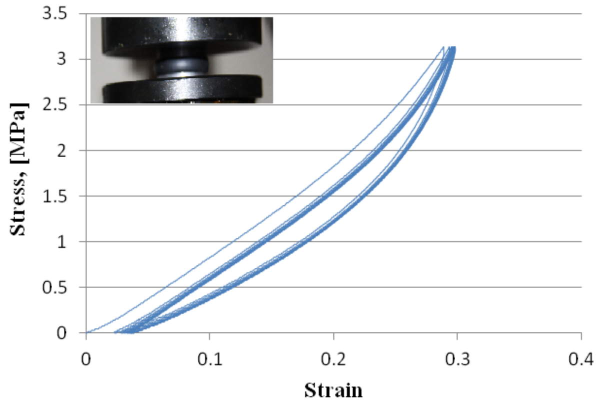

Fig. 7 – Stress–strain curves of NR specimen.

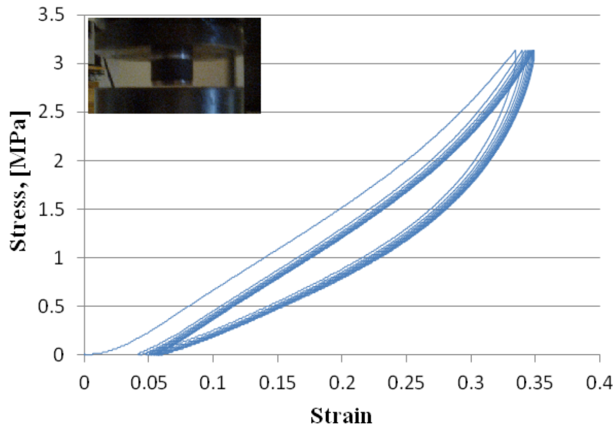

Fig. 8 – Stress–strain curves of NR/BR specimen.

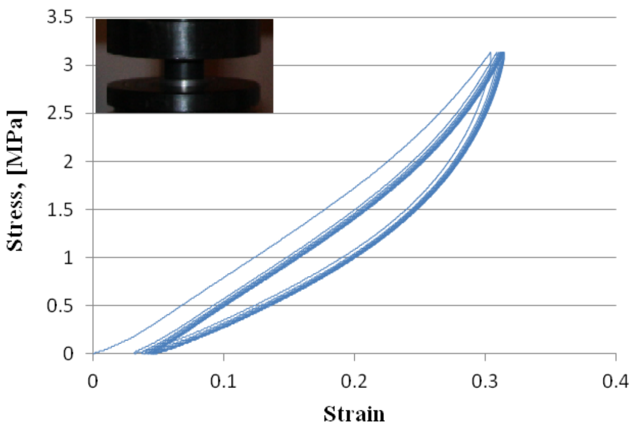

Fig. 9 – Stress–strain curves of NR/BR/SBR specimen.

The hysteresis loop of CR specimen are stabilized at cycle 6, NR specimen at cycle 5, NR/BR specimen at cycle 7 and NR/BR/SBR+PA/PE fibres at cycle 5.

5. Conclusions

The compression modulus of elastomers depends on their shape factor and hardness. In this paper the compression modulus was determined for four elastomer specimens with different compositions, both theoretically and experimentally. The results of this study indicate experimental values, E_{cs}, closed to the theoretical ones, especially with the relationship suggested by Gent and Lindley, E_{c2}.

In conclusion many relationships were developed to determine the compression modulus, however it is necessary to carry out experimental tests according to the test standards to verify the characteristics of the elastomers.

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MODULUL DE ELASTICITATE LA COMPRESIUNE AL ELASTOMERILOR

(Rezumat)

În ingineria civilă elastomerii sunt utilizaţi, în general, la reazeme pentru poduri şi la izolarea seismică a clădirilor situate în zone seismice.

Se prezintă principalele caracteristici ale elastomerilor, anume: duritatea determinată cu aparatul de testare Zwick, câteva relaţii pentru a determina modulul de elasticitate la compresiune a unui strat de elastomer şi rezultatele determinării experimentale a modulilor de elasticitate la compresiune ale unor epruvete din elastomeri cu compoziţii diferite: CR (cauciuc cloroprenic/neoprenic); NR (cauciuc natural); NR/BR (cauciuc natural/cauciuc butadienic); NR/BR/SBR+Fibre PA/PE (cauciuc natural/cauciuc butadienic/cauciuc butadien stirenic şi fibre de poliamidă/polietilenă). Testul la compresiune a epruvetelor din elastomer a fost realizat cu o Maşină Universală de Testare cu Control Electromagnetic WDW.

Scopul acestui studiu a fost de a cerceta şi defini relaţia de legătură dintre modulii de elasticitate la compresiune şi forfecare, factorul de formă şi duritatea elastomerilor. Rezultatele teoretice obţinute prezintă valori apropiate de cele experimentale.