MECHANICAL BEHAVIOR OF RUBBER SAMPLES UNDER RELAXATION

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Abstract. In the paper the relaxation properties of two types of rubber B10 and EPDM under constant strain are described. The experimental data, that is, the stress relaxation as a function of time was theoretically described using the Wiechert model with a serial connection between the piston and the spring. The model provided potential results for description of relaxation of the selected rubber materials.

Keywords: rubber relaxation, Maxwell model, Wiechert model, EPDM.

Introduction

The increasing of using rubber materials in many areas of modern technology leads to the necessity to describe with high precision the characteristics of short-term and long-term deformation and destruction of elastomeric structural elements. In terms of large deformations a linear approximation to describe the elastic properties of elastomers cannot be used, and should be considered as hyperelasticity material. In addition, the viscous properties of many elastomers depend on the characteristics of the deformation process, including the strain level, and are nonlinear [1]. These hyperelastic and rheological properties of the materials are interrelated and it is necessary to develop relevant methods of their determination. A low stress relaxation rate indicates high elastic properties of rubber, while a large relaxation rate indicates a high viscosity of rubber. The relaxation rate of stress is associated with such structural characteristics of rubber, as the molecular weight distribution in a ramified chain, gel content.

The work [2] considered at the same time the properties of viscosity and relaxation of rubber materials. Results of experimental researches and mathematical modeling by using of computational complex LS-Dyna are given in this work to predict the behavior of rubber materials under relaxation. The authors point out that the viscosity and stress relaxation are not equally dependent on the molecular weight. Thus, the methods for determining relaxation of viscosity and stress are important and supplement each other. However, the authors in their work indicate that for description that is more accurate in the behavior of the experimental curves it is necessary to take into account the given time.

Descriptions of the relaxation properties of rubber materials with the help of mathematical modeling are an actual problem today. Many authors have used different approaches for describing the behavior of rubber samples during the relaxation process. Often such type experiments are conducted under compression, but the tensile test has been considered in this work. There are also different standards for implementation of this experiment; samples of rubber have been taken according to the standard EN ISO 527.

Another paper [3] considered application of the generalized Maxwell model to describe the relaxation properties of concrete and frozen soil. During the research, the author obtained good results based on the computational and experimental data. Reducing of stresses in rubber – stress relaxation is a joint expression of the elastic and viscous properties of the material. We apply the generalized Maxwell model or it has another name as the Wiechert model for describing the behavior of the rubber material under relaxation.

The aim of this paper is to consider the Wiechert mathematical model for describing the behavior of rubber materials under relaxation, and comparison of the results for EDPM and rubber B 10.

Materials and methods

For preparation of this experiment Ethylene-Propylene-Diene-Monomer (EPDM) and rubber B10 were used. EPDM can compound to meet specific properties to a limit, depending first on the EPDM polymers available, then the processing and curing method was employed. EPDMs are available in range of molecular weights (indicated in terms of Mooney viscosity ML (1 + 4) at 125 ºC), varying levels of ethylene, third monomer, and oil content.

The test specimens were prepared in accordance with the relevant material specification. The specimens were either directly cut from the material in accordance with ISO 293, ISO 294 or ISO 295, as appropriate, machined in accordance with ISO 2818 from plates. All surfaces of the test specimens were without visible flaws, scratches or other imperfections. From moldy specimens all flash was removed taking care not to damage the molded surface. Test specimens from the finished goods were taken from flat areas or zones having minimum curvature. The rubber sample was tested for tensile in accordance with the standard EN ISO 527, and a sample of type 5A was used. The dimensions of the test specimen are presents in Fig. 1.

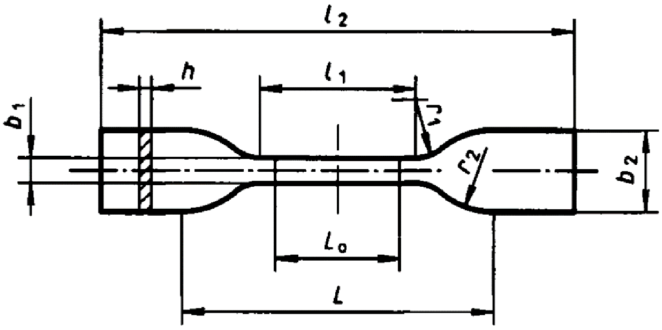

Fig. 1. **Test sample – Relaxation test (EN ISO 527-1:1993).** Overall length l_2– 75 mm, width of ends b_2 – 13 mm, Length of narrow-parallel sided portion l_1 – 25 mm, width of narrow-parallel sided portion b_1 – 4 mm, small radius r_1 – 8 mm, large radius r_2 – 13 mm, initial distance between grips L – 50 mm, gauge length L_0 – 20 mm, thickness h – 2 mm

The temperature in the laboratory was equal to 22 degrees on Celsius.

Relaxation test of rubber

These samples have been loaded at 60 % by force of explosive loading and then the load gradually decreased. For rubber B 10 the speed of testing was equal to 200 mm·s^{-1}, after reaching 27 N deformation it was equal to 36 mm, then the rubber sample was gradually unloaded with speed – 1 mm·s^{-1}. For EPDM rubber the speed of testing was equal to 200 mm·s^{-1}, after reaching 86.2 N deformation it was equal to 54.83 mm, then the rubber sample was gradually unloaded with speed – 1 mm·s^{-1}.

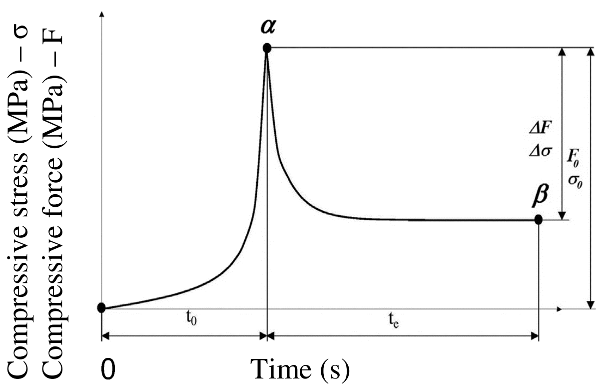

Fig. 2. Scheme of relaxation characteristic.

The relaxation forces were transformed into stresses by Eq. 1. The determined dependencies of relaxation stress and relaxation time were transformed into the normalised stress described by Eq. 2.

$$\sigma = \frac{F}{S}, \tag{1}$$

where F – relaxation force, N;
S – cross-sectional area, mm^2.

$$\sigma_n = \frac{\sigma_A}{\sigma_I}, \tag{2}$$

where σ_A – relaxation stress, Mpa;
σ_I = 2 for rubber B10 and σ_I = 6.6 MPa for EPDM.

Relaxation model

For description of relaxation of rubber B10 and EPDM the Wiechert model was used [4]. The model was assembled as three parallel linked branches with the first and second branches containing a serially connected spring and dashpot, whilst the last branch contained only a spring (Fig. 3). Mechanical behavior of relaxation involves the compliance of the condition of constant deformation (x_0 constant) and constant strain (ε_0 constant).

$$\sigma_A(t) = E_{A1} \cdot \varepsilon \cdot e^{-\frac{E_{A1}}{\eta_{A1}} \cdot t} + E_{A2} \cdot \varepsilon \cdot e^{-\frac{E_{A2}}{\eta_{A2}} \cdot t} + E_{A3} \cdot \varepsilon, \tag{3}$$

where E_{A1}, E_{A2}, E_{A3} – modulus of elasticity for the model branches, MPa;
η_{A1}, η_{A2} – coefficients of normal viscosity of the model branches, Mpa·s^{-1};
t – the time of relaxation, s.

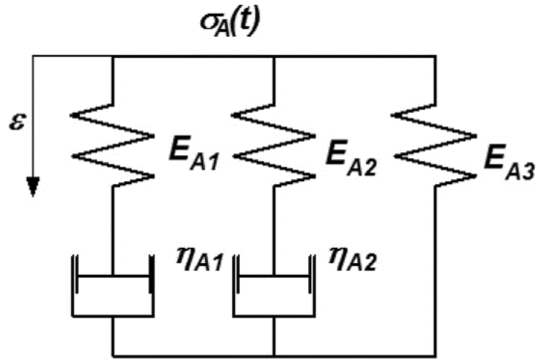

Fig. 3. **Scheme of Wiechert model**

The model (Eqs. (3)) was considered only in relaxation areas, i.e. between the points α and β as indicated in Fig. 2. The relaxation stress and appropriate times for the Wiechert model equations (Eqs. (3)) were analyzed using Mathcad 14 Software (MathCAD 14, PTC Software, Needham, MA, USA) [5], which uses the Levenberge-Marquardt algorithm for data fitting [6].

Results and discussion

During the experiment the relaxation curves of two types of rubber were obtained. Rubber is anisotropic material and the interatomic distances, elastic properties allow to lengthen much more than its original state, as during the test tensile rubber was prolonged for 90 mm, but the initial length was 25 mm. Most of the physical relaxation happens during the first moments after deformation.

Table 1

Statistical analysis of the Wiechert model

Type of rubber	F_r	F_C	P_V	R^2	E_{A1}, MPa	E_{A2}, MPa	E_{A3}, MPa	η_{A1}, MPa·s^{-1}	η_{A2}, Mpa·s^{-1}
Rubber B 10	0.001	4.351	1	0.99	0.0755	0.0831	0.5902	0.0009	0.0576
EPDM Rubber	0.001	4.085	1	0.99	0.1662	0.1747	1.2192	0.0039	0.1116

F_r – value of the F-test, F_C – critical value, P_V – hypothesis of the study outcomes significant level, R^2 – coefficient of determination

The Wiechert modelis used to provide the experimental description of the stress relaxation curves for both rubbers and is shown in Fig. 4. The coefficients of this model for the different strain values of rubber samples were determined by using the Levenberge-Marquardt algorithm [6]. An ANOVA

(Analysis of variance) statistical analysis using the MathCAD software of the measured and fitted data (Eq. (3)) showed that the Wiechert model [7] could mathematically describe the dependency on compressive stress and relaxation time. Individual elements of the Wiechert model are defined as follows: springs to describe the elastic component whilst the dashpots describe the viscous part; and these elements describe the behavior of the compressed material especially in terms of its rheological behavior.

Additionally, the Wiechert model implies that at the beginning of the relaxation process the springs are immediately subjected to deformation, expansion until an equilibrium state is reached, and the dashpots begin to move. This is dependent on the time, where deformation of these elements is directly proportional to the loading. After the system releases, the spring returns to its original state but the dashpots remain displaced [4]. However, based on the present experimental data, the Wiechert model showed better accuracy of the relaxation process, which can be used for analysis of the viscoelastic behavior of rubber. The only limitation of the Wiechert model is that its mathematical description (Eq. (3)) consists of fiveconstants, which need to be determined using the nonlinear fitting process, for example, the Levenberge-Marquardt algorithm.

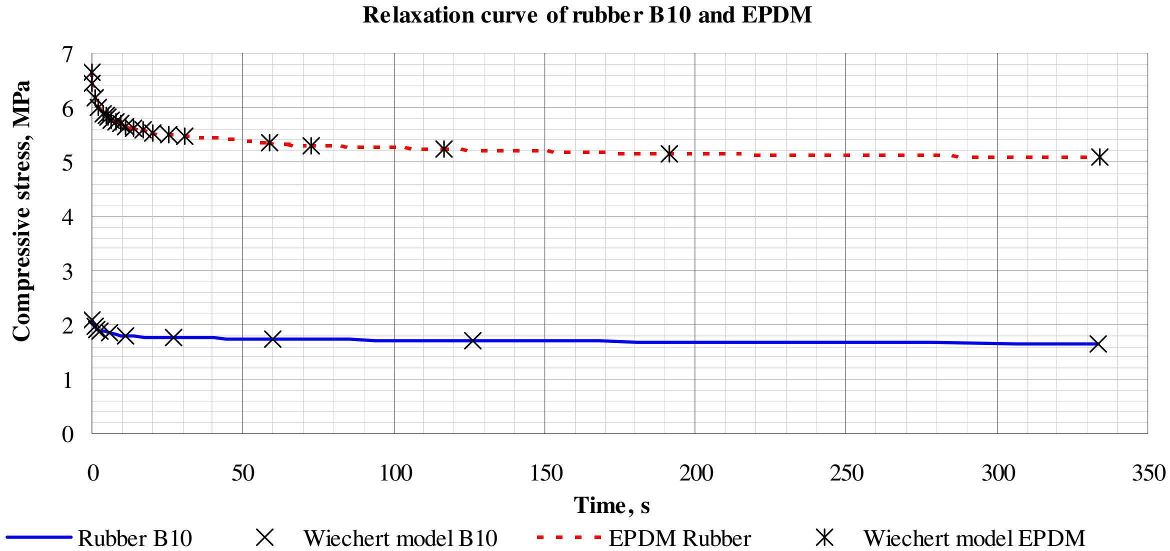

Fig. 4. **Results of the experiments and data obtained by the Wiechert model**

The relaxation curves of rubber samples, built according to the obtained data, are shown in Fig. 4. This coincidence of the calculated and experimental values shows that the mathematical Wiechert model is also applicable to predict the behavior of the rubber material during relaxation. Speed of unloading on the test machine is equal to 1 mm/min. The results obtained by the authors [2; 3] do not give such convergence results.

There is a small error in the construction of the calculated data points on the time axis, as seen from the curves in the graph. In general, the curve that is constructed by modeling coincides with the experimental.

Normalized stress for each sample is shown in Fig. 5 and it is evident that rubber B10 has exhibited bigger resistance against relaxation than EPDM. At the beginning of the relaxation process both samples have similar mechanical behavior, however, after ten seconds of relaxation the relaxation behavior of each sample becomes different. Using of rubber with good resistance property to relaxation will allow to exploit this material for creation shock absorbers and isolators (rubber and rubber-metal shock absorbers). Rubber is the basic element in the rubber-metal shock absorbers, since they possess elastic properties, which allow them to dampen vibrations of the structure.

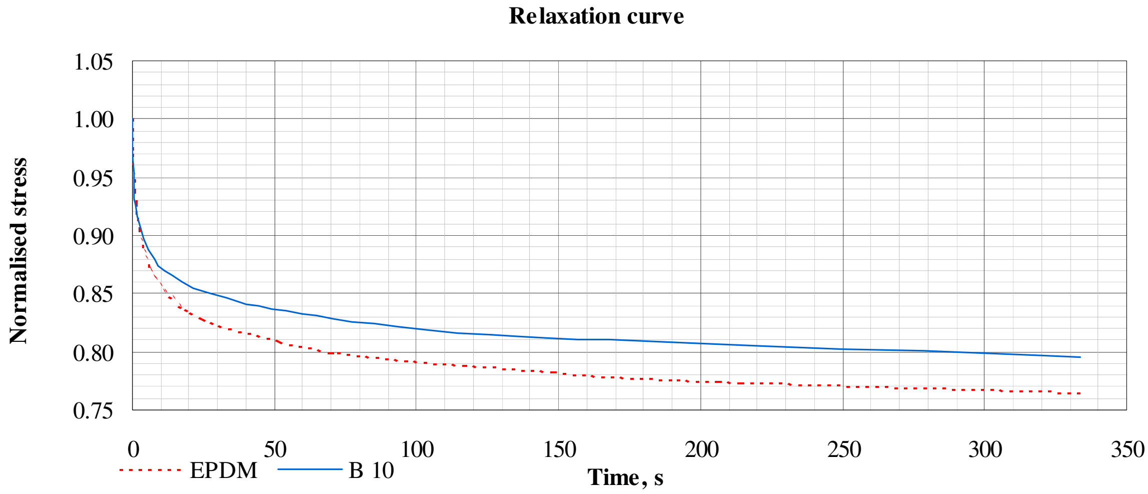

Fig. 5. **Relaxation curves of rubber B10 and EPDM**

Conclusions

From the conducted experiment, rubber under uniaxial tension has been described and the mechanical properties under the relaxation test of rubbers by using the Wiechert model. Stress relaxation is defined as decreasing under stress with the times under constant deformation. In rubber, stress relaxation occurs due to slipping of entanglements loosening the network of molecular chains, so they apply less force. The data obtained during the experiment show that for determination of relaxation of the rubber specimen the tensile test can be used. In contrast to work [2], the generalized Maxwell model (Wiechert model) has been used for precision description of the behavior of a rubber material, and it has been confirmed that this model describes the relaxation process quite well.

As seen from Fig. 5, the relaxation curves for rubber B10 and EPDM are different from each other. The relaxation curve for rubber B10 showed that more elastic material with higher viscosity allows to use it as amortization rubbers. Also it is known that such rubbers are used for the design of the rubber metal elements in nodes of machines.

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