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Test Method

Estimation of the energy dissipation capability for chosen elastomers with application of DMA

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ABSTRACT

The capability of material for energy dissipation is determined through analysis of the complex stiffness moduli. The imaginary part of complex stiffness modulus is proportional to energy dissipation per volume material unit. This estimation is justified when material works in its linearity range (the Boltzman principle is satisfied). In case when elastomers linearity range is crossed almost in all practical application like damping pads, bridge bearings etc. and another method should be used. Pseudo-elasticity phenomena may be observed for elastomers used in civil engineering except its viscous properties. For pseudo-elasticity there is no permanent deformation after unloading and no delay of the material answer with regard to its excitation but energy dissipation is still observed. In the paper the proposition of the particular test carried out for large deformation used for energy dissipation estimation is presented. Five different elastomers are evaluated with this method also with statistical analysis. The influence of the temperature and stress application velocity is investigated and analyzed. The obtained results are presented in the frame of standard methods, main differences are indicated, proving the need for different test method for estimation of material energy dissipation capability.

1. Introduction

The paper is a continuation of the research presented in paper [1], where results of the tests carried out on elastomers used for bridge bearings production were presented. In the mentioned paper the master curves of complex stiffness modulus were shown, the phase transformation temperatures were determined using three different criteria and indentation test results were presented. On that basis, the estimation of particular materials was made regarding their usefulness for technical applications. The effect of natural aging through almost 30 years was additionally investigated by comparison with original material.

Present paper supplements and extends the research presented in Ref. [1]. Both new materials and additional tests were added, one of which is a proposition of test allowing the estimation of material's energy dissipation capability in large deformation range [2,3]. A typical test allowing the determination of dissipative material properties is carried out in small deformation theory, and its interpretation results from the interpretation of the imaginary part of stiffness complex modulus [4,5]. It should be noted that elastomers often deform significantly revealing their non-linear material characteristics [6–8]. The relationship between strain state and stress state is non-linear, and cyclic tests reveal such phenomena like for example Mulin's effect, pseudo-elasticity or large deformation viscosity [7,8]. Conducting tests in complex stress states for significant deformations while maintaining homogeneity of stress or deformation fields requires the use of fairly sophisticated measuring equipment that is not always available in the laboratory [3,9]. In this work, it is proposed to use a DMA rheometer (Dynamic Mechanical Analyzer) typically used to perform tests in the small strain regime for testing materials undergoing significant deformations [10–13]. Large deformation term may be interpreted only on the theoretical basis. In case of so called “small displacement” or “small strain” linear or non-linear theory of elasticity (or different material property) the configurations of the body are not distinguished. So the differentiation (geometrical equations, balance equations, etc.) or integration (total energy, etc.) is always made on the same region. For large deformation theory the configurations of the body during loading are characterized (reference configuration, actual configuration etc.) so we have stress and strain measures like in “small deformation” theory but also changing configurations described with “deformation gradient” tensor, see for example ref. [2]. In case of experimental testing the notion of “large deformation” is not so clear because it depends on the type of material tested. In case of experiments presented in the paper it is clear that the “large deformation” term is appropriate because the sample deflection is of the order of its height.

2. Materials chosen for testing

Five different types of materials used in the civil engineering for the

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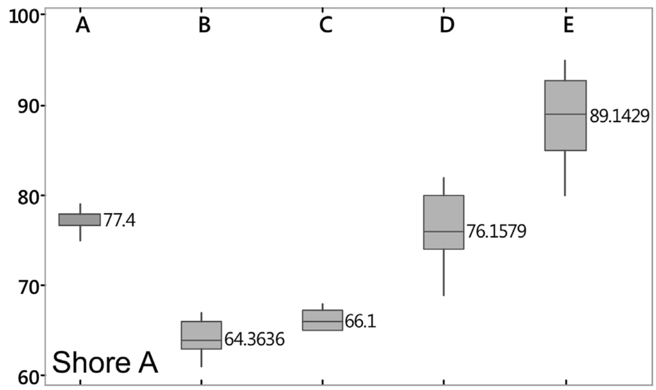

Fig. 1. Shore's hardness (scale A) – statistical analysis of obtained results.

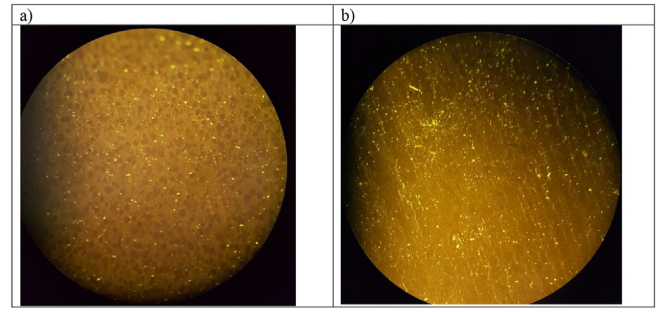

Fig. 2. The view from fluorescent microscope: a) material D (visible hollows after cutting through the pores), b) a typical elastomer used for production of bridge bearings (material B) - 50× magnification.

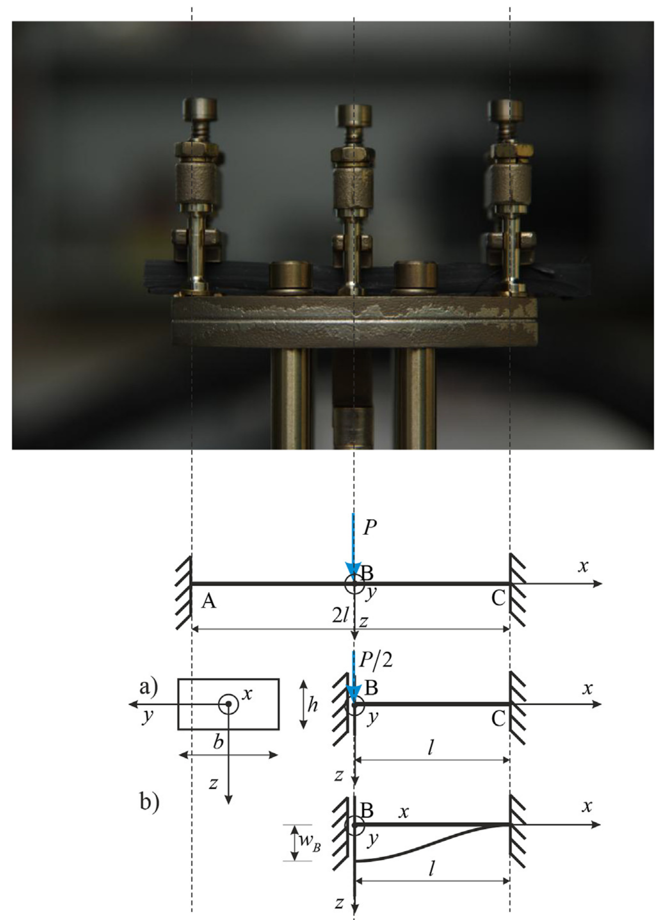

Fig. 3. View of the "dual cantilever" setup and beam scheme essential for the interpretation of the test results (a) - static scheme of a half-problem, (b) -w_B displacement interpretation.

production of elastomer bearings and materials used for damping of vibrations transmitted to the structure were selected for the research [14–17]. The materials are marked with the following letters of the alphabet: A, B, C, D and E (A-C refer to identical materials as in Ref. [1]). The materials were initially evaluated in terms of their Shore's hardness (on the A scale). The obtained results were statistically developed and presented in Fig. 1. When comparing the obtained results, it can be stated that the selected materials are significantly different (from the statistical point of view there is no difference between materials A and D as well as between B and C).

The first material tested in this work (material A) comes from an elastomer bearing made by Zakłady Gumowe Górnictwa in Bytom in the eighties of the last century. Detailed information concerning the chemical composition of this material and the method of sampling can be found in Ref. [18]. The 0.6 MN capacity bridge bearing made of this material was tested in the IBDiM laboratory in 1987 and since then it has been stored at room temperature without exposure to UV radiation for nearly 30 years. As the chemical composition of the elastomer used for this bearing is known, in 2016, an analogous material was produced in the Research and Experimental Plant of Elastomeric Technology of the Institute of Engineering of Polymer Materials and Dyes in Piastów, which can be treated as a reference material (i.e. unaged). This material is marked as C. It should be added that materials A and C are so-called synthetic rubber (chlorine rubber). In order to be able to compare this historical material with materials currently used for the production of elastomeric bridge bearings, the material marked as B was also tested. Unfortunately, its composition is covered under trade secret. Therefore, it is only known as a rubber based on natural rubber (NR) and meets the requirements of the PN-EN 1337 [19,20]. This material is widely used for the production of bridge bearings by a leading Polish manufacturer. Another material designated as D is used for vibration damping from the structure or inside the structure. The chemical composition as in the case of material D is under trade secret, however it is known that its neoprene/EPDM closed cell sponge type of material (closed pores filled with air), see Fig. 2, which shows a cross-sectional image of the material at 50× magnification obtained under a fluorescence microscope.

The last of the materials tested in this work (material E) is used for the production of pads for railway or tram rails by their leading manufacturer in Poland (polyurethane based). These pads are supposed to suppress the vibrations caused by rail vehicles moving on tracks to the surrounding railway infrastructure (historic buildings), etc. The chemical composition of this material is also under trade secrets.

3. The interpretation of the test results carried out in DMA in dual cantilever mode

All tests whose results are further presented and analyzed were carried out in the DMA rheometer (DMA Q800 TA Instruments) [21]. The research was carried out mainly in the so-called "dual cantilever" mode on prismatic samples that were cyclically bent using displacement or force steering signal. In case of using the "dual cantilever" setup, the problem of beam bending is analyzed as shown in Fig. 3.

In order to solve the problem, the differential equation of Bernoulli's beam was solved assuming no loading in the beam domain, i.e. $p(x) = 0$ with boundary conditions of the first type (cf. Fig. 3a)

$$\left.\frac{dw(x)}{dx}\right|_{x=0} = 0,\quad T(0) = -P/2,\ w(l) = 0,\quad \left.\frac{dw(x)}{dx}\right|_{x=l} = 0, \tag{1}$$

where $T(x)$ stands for shearing force in the beam $\left(T(x) = -EJ\frac{d^3w(x)}{dx^3}\right)$. Adoption of the boundary conditions of the first type means that in the analyzed beam bending test the steering signal is the force signal. The