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Procedia Engineering 117 (2015) 938 – 944

Procedia Engineering

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International Scientific Conference Urban Civil Engineering and Municipal Facilities, SPbUCEMF-2015

Peculiarities of Mechanical Characteristics of Contemporary Polyurethane Elastomers

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Abstract

Variants of design modification of absorbing units with elastic polyurethane elements are considered. The role of friction for achieving the required energy absorption is described. Reasons for instability of elastic characteristics and methods of eliminating instability are analyzed.

Peer-review under responsibility of the organizing committee of SPbUCEMF-2015

Keywords: Elastomer, polyurethane, Adiprene, Vibrathane, stress.

1. Introduction

Elastomers can be considered unique materials due to a number of their parameters. Their mechanical characteristics are several orders different from the usual characteristics of metals (mainly steels), that we are accustomed to. Elastomers allow the ultimate resilience ε^*_ν up to 1000 %, i.e. actually three orders higher than steel. They also provide energy dispersion owing to internal friction up to 60 % for one loading cycle, 3-4 orders higher than steel's indices. These materials demonstrate minimal material compressibility and their modulus of elasticity (Young's modulus) at compression exceeds by three orders the normal Young's modulus. In addition, elastomers experience relaxation of stresses at normal temperatures. That is why the loading rate influences the tests' results while the pre-loading force is reduced with time.

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1877-7058
Peer-review under responsibility of the organizing committee of SPbUCEMF-2015
doi:10.1016/j.proeng.2015.08.180

2. Target setting

A peculiarity of elastomers is a very wide range of mechanical characteristics (just like the entire class of polymers). However, in advertising booklets published by elastomer manufacturing companies the data regarding relaxation, dependence of hardness on loading rate and the form of operating character (which are important for design of elastic elements) are often missing.

3. The analysis of recent investigations and publications

Monograph (Artiukh, V.G., 2008) contains a complex analysis of the required properties and mechanical characteristics of elastomers that are applied for shock absorption of dynamic loads in heavy-engineering products, manufactured for iron and steel works. Artiukh, G. V. (1998) systematically studied the problems of stability of characteristics of shock-absorbers with elastic polyurethane elements. A number of experimental studies were conducted to define the energy absorption characteristics (overall energy capacity, specific energy capacity per unit of weight and volume) (Artiukh, G.V., 1999). An appliance for investigation of relaxation in polyurethane elastomers was proposed by Artiukh, G.V. (1998). Application of polyurethanes in metallurgical machines was analyzed in the works of Artiukh, G.V. (2004); Mazur et al. (2012); Firas et al. (2012). Application of polyurethanes in construction was studied in the works of Ubaydulloyev (2013); Smorchkov et al.(2012); Iskhakov et al. (2012); Absalyamov (2012); Sokolov (2011); Sokolov (2010); Bourdonov et al. (2012); Ulybin et al.(2014); Kurlapov et al. (2009); Gorshkov and Vatin (2013); Gorshkov et al. (2014); Simbort (2011); Ptukhin et al. (2014); Vatin et al. (2015); Nemov et al. (2015); Radovanović et al. (2015); Melnikov et al. (2015).

4. The article's objective

The objective of this article is to investigate thoroughly the mechanical characteristics of certain new elastomers to establish their application domain (the areas of most effective use for each elastomer), and make it easier to order materials with the required properties.

5. The materials and results of the investigation

The bulk of the group of elastomers consists of structural molding polyurethanes that have found wide application in machine building within the last two decades. A material named Adiprene by its manufacturers may be distinguished among polyurethanes. In most cases this is either Adiprene L-167 or Adiprene L-100, and occasionally, L-315. These materials proved successful for practical applications. They have a wide range in hardness and exploitation temperature, high internal friction (about 30-60%) but are subject to appreciable relaxation at pre-loading.

New polyurethane elastomers have appeared lately. These are three-component polyurethanes of Vibrathane and Elast type. Five specimens were selected for comparative testing:

- Vibrathane ShA 85
- Elast ShA 85
- Adiprene ShA85
- Adiprene ShA 90
- Adiprene ShA 95

The specimens were each shaped as hollow cylinders (Figure 1). Their dimensions are listed in Table 1.

The specimens were tested on a machine equipped with a mechanical drive ME-20UM (Figure 2) with the maximum force P^* = 20 кН at a loading rate V = 20 mm/min (Table 2).

Diagrams of compression of the materials listed above are given in Figure 3a,b. On the basis of these diagrams the values of elasticity modulus of the tested materials were calculated. The obtained results are listed in line three of Table 3.

We were particularly interested in the value of elasticity modulus at compression, obtained at different rates of loading. Tests were conducted at different rates of loading, at 5; 10; 20; 40 and 60 mm/min, according to the machine's capacity. The results of the tests are represented in Table 3 and in graphs (Figure 4).

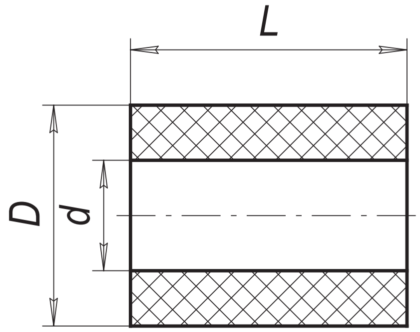


Fig. 1. Specimens for testing

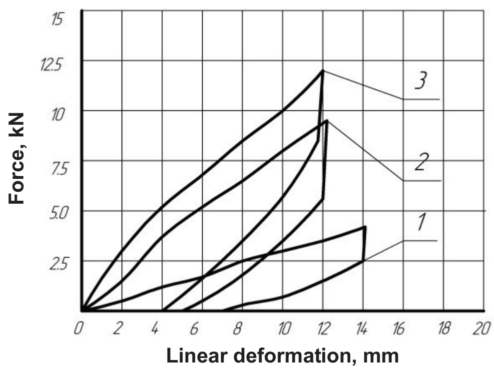
Fig. 2. Small-size desk-type testing machine

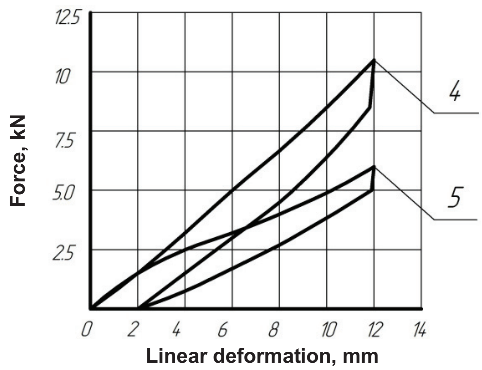
Table 1. Dimensions of the specimens tested

Dimension	Dimensions, [mm]				
	Adiprene ShA 85	Adiprene ShA 90	Adiprene ShA 95	Vibrathane ShA 85	Elast ShA 85
L	70	60	60	60	60
D	60	55	55	55	55
d	30	22	20	20	30

Table 2. Main technical characteristics of testing machine

The ultimate load, [kN]	20
Width of the operating space, [mm]	175
Travel of active gripping, [mm]	310
Range of travel rates of active gripping, [mm/min]	0.5 to 60
Power consumption, [Wт]	300
Dimensions, [mm]	680-480-200
Weight, [kg]	60





1 – Adiprene ShA 85; 2 – Adiprene ShA 90; 3 – Adiprene ShA 95;

Fig. 3a. Compression diagram.

4 – Vibrathane ShA 85; 5 – Elast ShA 85.

Fig. 3b. Compression diagram.

Table 3. Influence of the loading rate and hardness

Relative deformation rate, [1/sec]	Young's modulus, [MPa]				
	Adiprene ShA 85	Adiprene ShA 90	Adiprene ShA 95	Vibrathane ShA 85	Elast ShA 85
0.08	9.92	21.22	29.22	24.86	17.08
0.17	12.23	25.72	35.42	25.22	19.47
0.33	13.84	26.49	37.02	26.07	19.47
0.67	15.69	29.71	37.95	24.98	19.47
1.0	17.88	32.15	38.72	24.98	19.47

It can be seen in these graphs and Table 3 that the highest influence of velocity upon the material's hardness was revealed on the Adiprene samples. The ratios for relation of elasticity modulus at the highest (60 mm/min) and the lowest (5 mm/min) velocities were highest for Adiprene polyurethanes of (1.33…1.80) type and the smallest for materials of Vibrathane and Elast type (correspondingly).

It should be noted that the two materials, Adiprene and Vibrathane, possess a limit rate and exceeding this limit does not impact the elasticity of the material. These are very important characteristics, allowing us to forecast the material's behavior at shock loading.

The majority of pieces made from structural polyurethanes are elastic elements such as buffers, compensators, dampers and adapters. Parts are tested in laboratory conditions at static loading as a rule, yet they have to operate on machines with high loading rates. That is why the material's characteristics under dynamic loading at $V \geq V^*$ are of great importance.

Preliminary tests show that new polyurethanes Vibrathane and Elast possess such maximum velocity:

a) Vibrathane: $V^* = 40$ mm/min,

b) Elast: $V^* = 10$ mm/min.

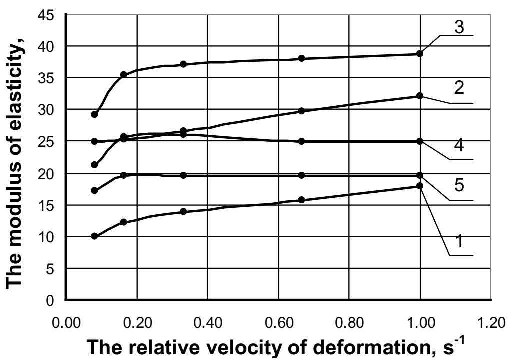
When we convert these into relative compression deformation we have:

a) Vibrathane $\varepsilon^* = 1 \cdot 10^{-2}$ 1/sec

b) Elast $\varepsilon^* = 0.25 \cdot 10^{-2}$ 1/sec

These are quite real loading rates that can be obtained on serial testing machines. The stable characteristics of hardness are very important for shock absorbers. For instance, the shock absorbers of railway cars have to operate at different rates to buffer the impact of joining the cars. It is worthwhile mentioning here, that Adiprene, a very wide-spread polyurethane, does not have this valuable capability. It can be seen in Figure 4 that the normal elasticity modulus of this material grows with increase of the loading rate.

Now, we can consider stability of characteristics of hardness from the other side: the value of deformation.



1 – Adiprene ShA 85; 2 – Adiprene ShA 90; 3 – Adiprene ShA 95; 4 – Vibrathane ShA 85; 5 – Elast ShA 85.

Fig. 4. Influence of the loading rate upon rigidity

The tests conducted showed that only one material – Vibrathane – at all stages of loading retains a characteristic that can be considered as linear. For the rest of the polyurethanes the compression diagram is convex. The highest value of compression modulus is observed at $\varepsilon_1 \leq 5$ %, then it is steadily decreasing until maximal planned deformation $\varepsilon^* = 20$ %.

That is why the listed values of the modulus for these materials become the value of “intersecting” (i.e. the average for $\varepsilon^* = 20$ %) modulus.

One more series of tests was conducted to investigate internal friction in elastomers. The value of ψ, % was determined at testing:

$$\psi = \frac{\int_0^{\varepsilon^*} P_{1\varepsilon} d\varepsilon - \int_0^{\varepsilon^*} P_{2\varepsilon} d\varepsilon}{\int_0^{\varepsilon^*} P_{1\varepsilon} d\varepsilon} \cdot 100\% , \tag{1}$$

where $P_{1\varepsilon}$ - is the curve of specimen’s loading;

$P_{2\varepsilon}$ – the curve of specimen’s unloading.

ψ – value was fixed at first (ψ_1) and fourth (ψ_4) consecutive loading. The highest value of ψ was received at the first loading: $\psi_1 > \psi_4$. This was observed for all materials. As far as absolute values of ψ are concerned the highest value of ψ was established in specimens, made of polyurethanes of Adiprene ($\psi = 60$ %) series, the smallest in Vibrathane and Elast ($\psi = 12$ %) polyurethanes.

This property can be decisive for the operation of a particular structure. So, for example, for buffers and dampers (energy absorbers and energy dissipaters) a high value of ψ is beneficial. It simplifies the appliance’s design because its external friction element is no longer required. Likewise, under cyclic forced oscillations a high value of ψ with poor heat conductivity will rapidly lead to overheating and thermal destruction of the elastic element. In this case a material with smaller internal friction, like Vibrathane or Elast will be appropriate.

The latest series of testing of all materials investigated relaxation of forces on specimens at a constant value of deformation. Deformation equal to 20 % was set for all specimens and the force acting upon a specimen was recorded for one hour following machine shut-down. Table 4 summarizes all measurements of forces, exerted upon the specimen under testing.

Table 4. Relaxation of efforts in specimens

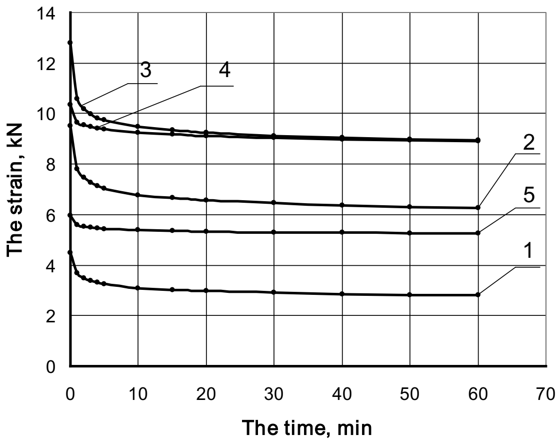
t, [min]	Load, [kN]				
	Adiprene ShA 85	Adiprene ShA 90	Adiprene ShA 95	Vibrathane ShA 85	Elast ShA 85
0	4.50	9.52	12.80	10.35	5.95
1	3.69	7.80	10.60	9.65	5.59
2	3.48	7.47	10.19	9.53	5.52
3	3.37	7.27	9.97	9.47	5.49
4	3.30	7.15	9.83	9.42	5.46
5	3.24	7.04	9.74	9.38	5.44
10	3.09	6.78	9.47	9.25	5.39
15	3.02	6.65	9.33	9.17	5.35
20	2.97	6.56	9.23	9.11	5.33
30	2.90	6.45	9.11	9.04	5.30

40	2.86	6.37	9.03	8.99	5.28
50	2.83	6.31	8.98	8.95	5.26
60	2.80	6.27	8.93	8.92	5.25

Residual values of the force after one hour holding under the load for five specimens are equal to (% of the original force):

1) 62;
2) 66;
3) 70;
4) 86;
5) 88.

Vibrathane and Elast are least susceptible to relaxation. These materials should be more effective, as compared to other elastomers being loaded with a constant load, for example in the system of balancing spindles of rolling mills, in preliminarily loaded shock absorbers, safety devices, absorbing apparatuses of railway cars etc. It can be seen in graphs (Figure 5) that Elast has the best relaxation values. This material could in some cases replace steel springs, having stable mechanical characteristics.



1 – Adiprene ShA 85; 2 – Adiprene ShA 90; 3 – Adiprene ShA 95;
4 – Vibrathane ShA 85; 5 – Elast ShA 85.

Fig. 5. Relaxation of efforts in specimens

6. Conclusions

1. Only one material - Vibrathane - has a characteristic that can be considered as linear at loading.
2. The normal Young’s modulus of Adiprene is growing with increase of the loading rate.
3. Vibrathane and Elast are the most efficient materials for being loaded with a constant (static) load.
4. Elast is the least susceptible to relaxation. It is capable of replacing steel springs in some cases.

Acknowledgments

The authors acknowledge the assistance given by Ralph Williams who thoroughly edited the final version of the paper in English, making it acceptable for publication.

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