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INSTALLATION FOR MEASURING STRESS RELAXATION IN POLYMER MATERIALS UNDER FRICTION AND WEAR CONDITIONS

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Abstract

The work assessed the need to predict the relaxation properties of polymers, which is important for ensuring the durability of parts of mechanical engineering structures made of polymer materials. The factors influencing the performance of products made of polymer materials, as well as the need to determine and predict the durability of parts operating under friction conditions at a constant amount of deformation, have been studied.
To determine by experimental method the stress relaxation indicators of polymer materials under conditions of friction and wear, a device has been developed - a triborelaxometer. A description of the installation design, loading and loading conditions, as well as the coefficient of friction in the polymer-counterbody pair is given.

Keywords: *stress, deformation, relaxation properties of polymer, friction and wear, computer equipment, triborelaxometer.*

Introduction

Currently, polymer materials are widely used in the national economy, including mechanical engineering, to reduce the material consumption of structures, save energy, reduce labor costs, and also improve the quality, reliability and durability of products in the required time frame [1].

Polymer materials used in mechanical engineering are subject to specific requirements, including resistance to friction, durability and other material qualities.

However, to date they have not studied the processes of temperature, radiation, the influence of a liquid medium, vibration, friction and wear, taking into account the principles of relaxation on the mechanical engineering of polymer materials [2]. The production of polymer materials and obtaining goods from them in the case of relaxation processes with the study of analytical dependence, with the dependence of increasing the durability of materials to produce new important fundamental methods for research is the goal and objectives. This research consists of the following tasks.

The wear of polymer materials corresponds to the kinetic theory; damageability and strength over time must be characterized at a certain speed by the value of the integral [3].

Durability and solids, including studying the analytical processes of wear of polymers with this subsequent step-by-step expressions.

However, the laws of processes have not yet been studied, taking into account the relaxation in which engineering polymer materials, their temperature, vibration, radiation, the durability of products made of polymer materials, depending on their molecular and supramolecular structures, deformation, vibration, friction and wear, as well as on temperature and the environment are not fully reflected in analytical descriptions taking into account relaxation processes [4].

In this regard, the study of the durability of polymer materials under conditions of relaxation processes occurring in them under the influence of external mechanical and physical loads is an urgent problem in polymer materials science [5].

2.Method

It is known that the durability of polymer materials is determined by the analytical dependence of the durability of polymers on several factors [6], obtained by S.N. Zhurkov and his colleagues:

$$\tau = \tau_0 \exp\left[\frac{(u_0 - \gamma\sigma)}{RT}\right], \qquad (1)$$

Where τ_o - constant, close to the period of thermal vibrations of atoms (10^{-12} - 10^{-13} c);

u_o – energy of chemical bonds; γ - structural coefficient;

σ - voltage; R - Boltzmann constant;

T - absolute temperature.

However, this formula does not take into account the durability of polymer materials taking into account the stress relaxation process [7]. The dependence of stress during the relaxation process is described and determined by the following formula by T. Alfrey:

$$\sigma = \sigma_\infty^* \exp\left(\frac{u_0 - \gamma\sigma}{RT}\right), \qquad (2)$$

Where, $\sigma^*_\infty = E\alpha\tau_o$ - equilibrium stress;

σ- voltage; T - absolute temperature;

R - gas constant;

τ_o, u_o, γ - constant coefficients that determine the relaxation properties of the polymer; α - rate of strain growth due to thermal expansion;

E – elastic modulus.

Let's try to get S.N. Zhurkov's equation. taking into account the stress relaxation equation (2). To do this, we divide both sides of equation (1) by τ_0, we get the following formula:

$$\frac{\tau}{\tau_0} = e^{(u_0 - \gamma\sigma)/RT}, \quad (3)$$

Taking the logarithm of (3) relation, we find the following expression:

$$In\frac{\tau}{\tau_0} = (u_0 - \gamma\sigma)/RT,$$

from the last relation we find σ,

$$\sigma = \frac{1}{\gamma}\left(u_0 - RT\ln\frac{\tau}{\tau_0}\right), \quad (4)$$

Comparing (4) and (2) relations, we have the following equation:

$$\frac{1}{\gamma}\left(u_0 - RT\ln\frac{\tau}{\tau_0}\right) = \sigma_\infty^* \exp\left(\frac{u_0 - \gamma^\sigma}{RT}\right), \quad (5)$$

The last relation is equivalent to the following expression:

$$\ln\frac{\tau}{\tau_0} = \frac{1}{RT}\left(u_0 - \gamma\sigma_\infty^* \exp\frac{u_0 - \gamma^\sigma}{RT}\right), \quad (6)$$

From expression (6) one can find

$$\frac{\tau}{\tau_0} = e^{\left[\frac{1}{RT}\left(u_0 - \gamma\sigma_\infty^* \exp\frac{u_0 - \gamma^\sigma}{RT}\right)\right]}, \quad (7)$$

From here we find τ and obtain the following equation - the Negmatov-Norkulov equation [8], which describes the durability of polymer materials taking into account the relaxation stresses in them:

$$\tau = \tau_0 \cdot \exp\left\{\frac{1}{RT}\left(u_0 - \gamma.\sigma_\infty^*.\exp\frac{u_0 - \gamma^\sigma}{RT}\right)\right\}, \quad (8)$$

Based on the above, we have obtained an equation that describes and predicts the durability of polymer materials taking into account relaxation stresses in them [9]. The durability of polymer materials used in mechanical engineering in the process of stress relaxation can use equation (8).

When calculating parts made of polymer materials operating under stress relaxation conditions, it is very important that the value of the equilibrium stress does not fall below the required stress value σt depending on their operating conditions [10]. For the calculation, in principle, it is not necessary to take σ∞, but you can take σt equal to the time corresponding to the service life of parts or products. To predict the relaxation properties of materials over long periods of time and take into account the effect of temperature on their mechanical properties, thermo-, baro- and time analogies can be used [11].

It is known that the equilibrium stress is a function of the rate of deformation, the shape of the sample, the initial stress, the degree of cross-linking of macromolecules, temperature, exposure to the environment, irradiation, wear, etc [12].

However, under conditions of stress relaxation, destruction of materials occurs. Therefore, it is necessary to determine and predict the durability of parts operating under conditions of constant deformation. (ε = const) .

Stress relaxation in the presence of friction and wear is described by the equation:

$$\sigma_{изн} = \sigma_t - E \cdot A\left[t_n - \gamma^a \int_0^t e^{-\gamma(1+a)(t-\tau)}\tau^n d\tau\right]$$

Where: σ_t - equilibrium stress;

E – elastic modulus;

A, n – material constants;

γ, a – relaxation kernel parameters;

t - experience time;

τ - relaxation time.

As a result of substitution into the equation of S.N. Zhurkov we get [3].

$$\tau = \tau_0 \exp\left[\frac{U_0 - \gamma(\sigma_t - B)}{kT}\right],$$

Where, $B = E \cdot A\left[t_n - \gamma^a \int_0^t e^{-\gamma(1+a)(t-\tau)}\tau^n d\tau\right]$ - linear viscoelasticity coefficient; U_0 – energy of chemical bonds.

To obtain the performance area of a polymer material, the values σ_t, u_o and γ determined experimentally.

3. Results and Discussion

In order to determine the parameters of stress relaxation and the coefficient of friction of polymer materials with a solid body, a device was created for measuring stress relaxation of polymer materials under conditions of friction and wear, containing a frame with a test sample holder placed on it, a loading unit and measuring load and friction [13].

To measure stress relaxation indicators, it is equipped with a loading unit, a unit for measuring sample deformation, a friction force meter for the polymer material with the contacting sample, and the sample holder is made in the form of a disk mounted on the rotation axis (Fig. 1).

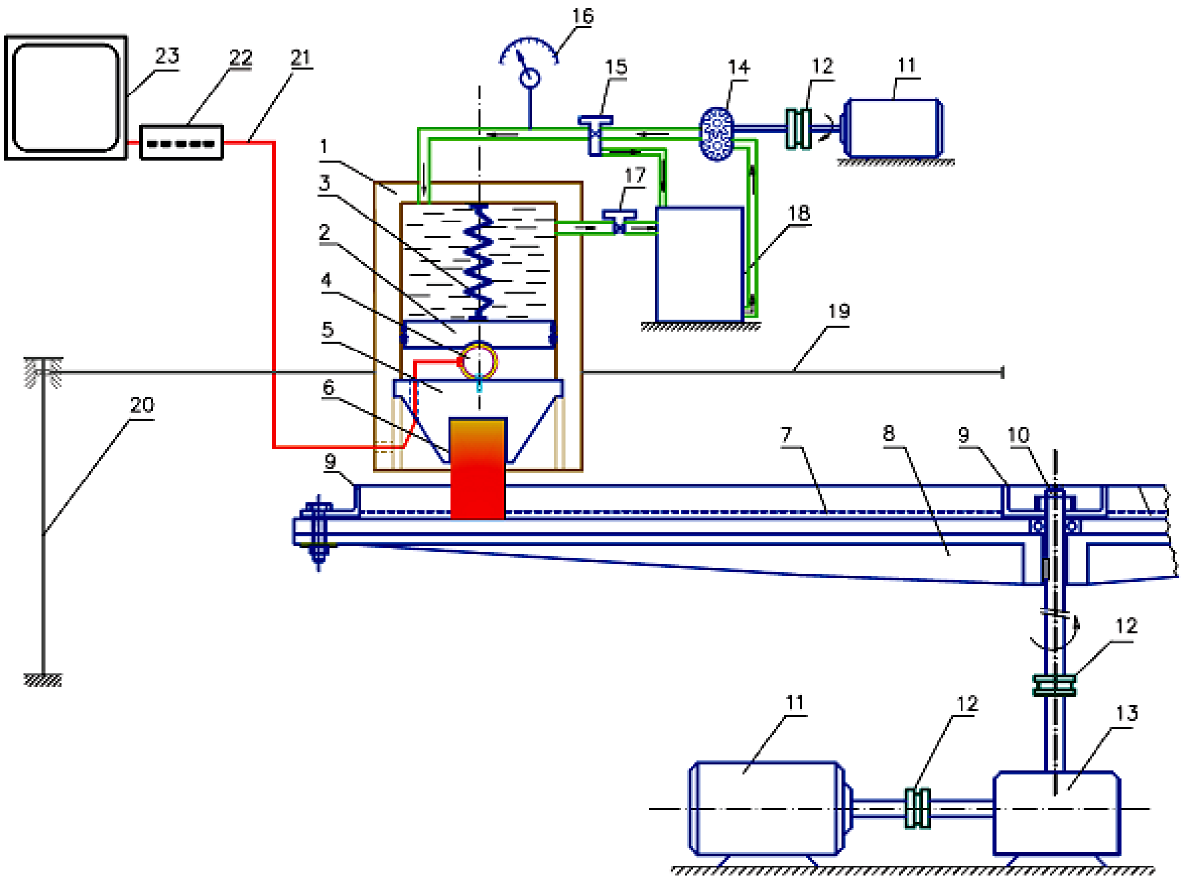

Figure 1. Schematic of a triborelaxometer for measuring stress relaxation of polymer materials.

The triborelaxometer contains a hydraulic cylinder 1 with a piston 2 and a spring 3 in the space above the piston, and in the space below the piston it contains a strain gauge ring 4 with strain gauges glued to it, a holder 5 in the form of a truncated cone, placed with the base upward and with the ability to move vertically in the hydraulic cylinder, test sample 6 , coating 7 of structural material applied to the support disk 8, groove 9 for supplying liquid when testing a sample for friction in a liquid medium, drive shaft 10, DC electric motor 11, clutch 12, gearbox 13 for driving the rotation of the drive shaft 10, gear a pump 14 for supplying fluid under pressure, which is set and controlled by a pressure reducing valve 15 and a pressure gauge 16, a container 18 for fluid supplied to the hydraulic cylinder 1 and a boom 19 to ensure horizontal movement of the hydraulic cylinder above the support disk 6, mounted on a stand 20 through a rolling bearing [14].

Strain gauge rings 4 and 25 with strain gauges attached to them are connected through wires 21 to the hardware and software complex 22 and to the monitor 23, which displays data in the form of graphic curves.

Figure 2 shows the relative position of straight splined grooves and semi-prismatic protrusions, as well as a cable 24 on which a strain gauge ring 25 with strain gauges is attached to record friction forces [15].

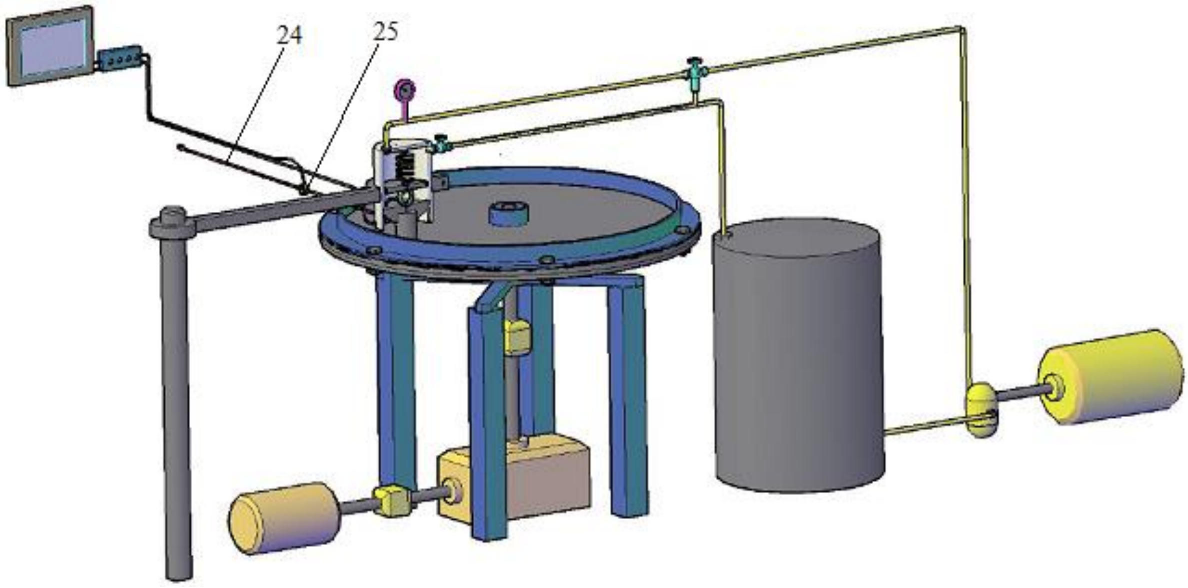

Figure.2. 3D model of a triborelaxometer for measuring stress relaxation of polymer materials.

The triborelaxometer operates as follows: into the hydraulic cylinder 1, mounted on the boom 19, with the ability to rotate around the axis 20 under the influence of friction forces, under a fixed pressure of 14 MPa created by the gear pump 14, liquid (water or mineral oil) is supplied from the container 18 through the regulating pressure, pressure reducing valve 15 and pressure gauge 16. Under the pressure of the liquid entering the above-piston space of the hydraulic cylinder 1, the vertical spring 3 and piston 2 move down, also exerting pressure on the strain gauge ring 4 with strain gauges placed on it, which is transmitted to the base of the holder 5, made in the form of a truncated cone into which a test sample made of polymer material 6 is placed, made in the form of a cylinder with an aspect ratio L/d=1.5. In this case, the holder 5, under pressure, lowers down vertically, due to the protrusions and spline-shaped slots 24 made in the walls of the hydro cyclone, pressing the test sample 6 with its base against the coating 7 of the test material of the support disk 8, driven into rotation in the horizontal plane by a DC electric motor 11 through vertical drive shaft 10, coupling 12 and gearbox 13, providing linear speeds from 0 to 9 m/sec along the friction radius. The optimal ratio of the friction radius to the diameter of the lower part of the hydraulic cylinder is 0.5 - 1.5.

The load to create pressure on the test sample 6 is controlled by a pressure reducing valve 15 and a pressure gauge 16. Excess liquid is discharged through the drain valve 17 into the original container 18. The study is carried out both in a dry environment and with liquid supplied to the friction area of the test samples [16].

Determination of the relaxation stress of a polymer sample 6 installed in the cavity of the holder 5 during friction is performed by compressing a strain gauge ring located between the piston 2 and the base of the holder 5, applying a load and creating pressure. Indicators of voltage magnitude and relaxation time are determined by a hardware and software complex 22 connected to a computer 23 via wire 21. The data is obtained in the form of a graph of the load versus relaxation time.

The magnitude of the friction force is determined by a strain ring 25 with strain gauges placed on a cable 24 attached to the base of the hydraulic cylinder, perpendicular to the plane of the boom, in the form of a frame 19, which are connected by wire to the software and hardware complex 22 and the computer 23. At the end of the work, the liquid from the hydraulic cylinder 1 is released through drain valve 17 into bath 18, as a result of which all elements of the device return to their original position [17].

To measure stress relaxation, the sample is deformed to a specified value, which remains constant over time, and the initial stress required to maintain this deformation decreases with time.

The use of the proposed modernized triborelaxometer makes it possible to significantly simplify the measurement of stress relaxation of polymer materials taking into account friction, due to the stability and compactness of the installation, reliability of measurements and accuracy, as well as through the use of a software and hardware complex for measuring indicators [18].

To evaluate the stress relaxation of polymer materials under conditions of friction and wear, the polymer material under study is used as a test sample, and any engineering materials and products with various types of surface coatings can be used as a counter body. The triborelaxometer allows you to measure stress relaxation parameters in polymer materials under friction conditions with higher reliability and accuracy of the indicators [19].

Table 1 shows the experimentally determined values of the parameters included in the calculated equations for the activation energy of the stress relaxation process and the structure-sensitive coefficient.

Table 1

Experimental values of the parameters of equation (8) for various polymer materials

Materials	Voltage, MPa			Temperature, K			u_0, kkal/ mol	γ, kkal /mol mm^2/kg
	σ_1	σ_2	σ_3	T_1	T_2	T_3		
Metholon	32,8	27,6	12,7	374	379	396	22,16	0,302
Phenylone	60,0	52,2	39,3	489	509	543	54,31	2,030

The table shows that methanol has a lower activation energy, which characterizes the stress relaxation process. A good agreement between the experimental data and the calculated data was established.

In Fig. Figure 1 shows the theoretical curves according to equation (8) and the experimental dependence of the durability of phenylone and metholone on the relaxing stress.

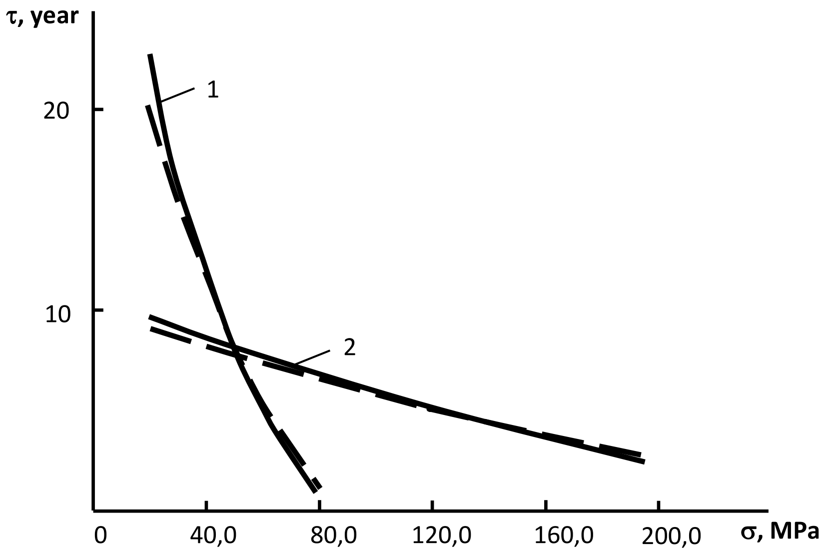

Figure 3. Durability relationship between phenylone and metholone

from relaxing tension. 1-phenolone; 2-metholone.

—— - theoretical curves, — — — - experimental curves.

It can be seen that with increasing voltage, the durability of polyamides decreases. What if the value of the initial stress is too high, then the polymer will find itself in harsh operating conditions and its durability, naturally, decreases, since the greater the value of the initial stress, the shorter its relaxation time.

4. Conclusion

Thus, the resulting generalized Negmatov-Norkulov equation makes it possible to predict the durability of engineering polymer materials taking into account stress relaxation. In turn, predicting the durability of materials allows you to correctly select and accordingly develop new polymer materials and products made from them, taking into account the specific conditions of their operation. For example, for parts and products made from the above polymeric materials, operating under stress relaxation conditions.

The use of a triborelaxometer makes it possible to significantly simplify the measurement of stress relaxation in polymer materials under friction conditions, due to the stability and compactness of the installation, and the reliability of measurements and measurement accuracy under specific conditions of friction of a polymer material with any structural materials is ensured using a software and hardware complex for measuring indicators.

The study of relaxation of polymer materials can be carried out both under dry friction conditions and under lubrication conditions. To measure stress relaxation, a sample of a polymer material is deformed to a specified value, which remains constant over time, and the initial stress required to maintain this deformation decreases with time.

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