Research of frost-resistant rubber for seals

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Abstract. As a result of experimental studies, the dependencies of the static modulus of elasticity of the five rubber compositions during bending on the temperature in the range from -70 to +100°C were established. The results of the temperature test simulating the change in contact stresses in the seal after installation at 20°C and subsequent cooling, as well as the temperature test, when the bending deformation is increased after cooling, are also presented. The dependences of the coefficient of friction of rubber on fluorine-containing coatings of three types and steel were experimentally obtained in a wide range of negative and positive temperatures. The design of the test bench for studying the elastic moduli during bending of rubber and polymer samples in a wide range of bending deformations and temperatures and the test procedure for it is described. A methodology for studying the coefficient of friction of rubbers during friction on fluorine-containing coatings and steel in a wide temperature range is presented. Friction coefficients were determined during unilateral rotational motion of flat samples at a sliding speed of 0.2 m/s, pressures on the friction surface from 0.8 to 50 MPa and a temperature range from -40 to +120°C.

1. Introduction
Seals made of elastomers and polymers which are operated in a wide range of low and high temperatures [1-5] are widely used in engineering. In particular, the consideration of the temperature factor is extremely important in the design and operation of fixed and movable seals made of rubber [6-9]. In the calculations of such seals, it is necessary to take into account the dependence of the elastic constants on temperature, as well as the effect of temperature on the coefficient of friction of rubber. At minimum sizes within tolerances, the seal must not leak at low temperatures, and at maximum sizes, it must not break at high temperatures. To ensure the operation of the seal, it must be tightened when installed in the socket to the maximum permissible values, that is, about 25%. This mode of operation can withstand only the highest quality and expensive rubber [9].

When assessing the magnitude of low-temperature leaks, a prerequisite is the inclusion of inelastic behavior of rubber. Under the influence of temperature in the rubber, plastic deformations occur. Unlike the traditional theory of plasticity, their value depends not only on the history and magnitude of loading but also on the magnitude of the temperature and the length of time during which the rubber experiences this load and temperature [10-17].

This work aimed to study the static elastic modulus depending on the temperature in the range from -70 to +100°C for five rubber compositions under the conditional names “56”, “101”, “985”, “205”, “207”, and also the study of the coefficient of friction of rubber during friction on fluorine-containing coatings and steel in a wide range of temperatures and pressures on the friction surface.
2. Research stand and test procedure

The installation diagram for studying the elastic modulus of elastomers in bending is shown in figure 1. Standard samples with a diameter of 8 mm and a length of the working part of the sample of 23.5 mm were tested under bending with a given strain amplitude, a given rotation frequency, and ambient temperature. Sample 1 is fixed in the clamps 5 in such a way that a bending angle \( \alpha \) is created, simulating the value of the angular misalignment of the shafts. One of the clamps is installed on the rotor of the electric motor 2, and the other on the free axis, the bearings of which are installed in the rack 6.

The rack 6 is mounted in the groove of the movable platform 7, mounted on a vertical axis. Rack 6 can be moved along a curved groove to specify arbitrary angles \( \alpha \), the scale of which 9 is plotted along the groove. The bending moment necessary for calculating the module is determined by the weight of the cargo 8, balancing the position of the platform 7. The platform is installed in a heat chamber that limits the volume indicated by a dotted line in figure 1.

![Figure 1. Installation diagram for studying the elastic modulus of elastomers.](image1)

The stand provides the angle \( \alpha \) to 90 degrees (deformation to \( a = 0.3 \)). Volume temperatures in the temperature range from +20 to +100°C inside the setup chamber were created by the heater. Negative temperatures were created by feeding liquid nitrogen into the cryostat. A general view of the stand is shown in figure 2.

![Figure 2. General view of the heating chamber in studies of the elastic modulus of elastomers.](image2)
Tests at temperatures other than 20°C were carried out in the following sequence. A rubber specimen with zero relative deformation was installed in the clamps of the device. At the same time, the entire batch of samples necessary for this series of tests (15–20 pcs.) was placed in the installation chamber in the container. Using a heater or a cryostat, a predetermined temperature was created in the chamber, which was maintained for 15 min for uniform heating or cooling of rubber samples.

After that, the specimen installed in the clamps was bent to the specified relative deformation \( a = 0.1\text{÷}0.3 \) and the bending moment was measured using balancing cargos. The balancing load was set with an accuracy of 0.01 N. Then, the tested sample was removed from the chamber, and a new sample was installed in the clamps at zero relative deformation from the container located in the chamber. A new temperature level was established and the procedure was repeated. In the temperature range from -70 to +100°C, measurements were carried out at 10°C.

3. The results of experimental studies

Figure 3 shows the temperature dependences of the elastic modulus \( E \) for bending \( a = 0.15 \) for five rubber compositions. In figure 3, the experimental points corresponding to rubber 101 are indicated by the symbol (○), rubber 207 by the symbol (□), rubber 56 by the symbol (×), rubber 205 by the symbol (◊), rubber 985 by the symbol (+).

![Figure 3. The dependence of the modulus of elasticity on volumetric temperature.](image)

Figure 4 and 5 show the temperature dependences of the modulus \( E \) of the studied rubbers under bending with a relative deformation of \( a = 0.15 \). Figure 4 shows the change in the modulus under constant deformation after cooling. This test simulates the change in contact stresses in the seal after installation at +20°C and subsequent cooling. In this case, “\( E \)” is an apparent module, as a result of measuring the bending moment. “Apparent” since it includes relaxation, heat shrinkage, the influence of loading speed, etc.
Figure 4. General view of the heating chamber in studies of the elastic modulus of elastomers.

Figure 5 shows the change in the modulus after cooling, followed by an increase in bending strain. This test simulates the change in contact stresses after installing the seal at + 50°C, and subsequent cooling and applying pressure.
4. Study of the coefficient of friction of rubbers on fluorine-containing coatings

The friction coefficients of HNBR rubber for fluorine-containing coatings of the XYLAN type were experimentally studied. The studies were carried out in the temperature range from -40 to +120°C and loads from 0.8 to 50 MPa. The coefficients of friction of motion were determined at sliding speeds of 0.2 m/s and one-way rotational motion of flat samples. The tests were carried out on a mechanical friction machine, the circuit diagram of which and a detailed description of the design are given in [9-11]. In studies to determine the coefficient of friction, the lower annular sample with a coating deposited on its end surface (figure 6) is mounted on the head of a vertical spindle. The upper sample, with rubber plates glued to its surface, is fixed in the holder using three screws.
Figure 6. The appearance of a sample with rubber plates and samples coated with XYLAN.

The holder is centered relative to the spindle by a self-aligning ball bearing, which allows free movement of the holder with the sample along their axis. The loading of the samples is carried out with loads mounted on a suspension bracket of a lever having a shoulder ratio of 1:10. The load from the lever is transferred to the upper specimen through the ball bearing.

Three HNBR rubber plates were glued to the end surface of the upper steel specimen at an angle of 120° (see figure 6). Coatings were applied to the end surface of the lower steel sample. Three types of coatings were studied: XYLAN P5211, XYLAN 5250/000, XYLAN 1014/748 [13]. The thickness of these plates was 2.5 mm, and their total area was varied from 25 to 100 mm² depending on the studied load range.

During tests, a plastic lubricant (FIOL-1) was applied to the surface of the samples and they were placed in the stand. Then the samples were loaded with minimal effort, the required temperature was created for testing, and the samples were friction with a sliding speed of 0.2 m/s. In this case, the value of the friction force and the temperature in the friction zone were recorded. Then, the load on the samples increased to its next value, and after standing at rest for 0.5 hours, the friction force was measured again. The results of experimental studies of the friction coefficients of HNBR rubber for three types of XYLAN and steel coatings at pressures on the friction surface of rubber of 2.8 MPa are presented in figure 7.
Figure 7. The appearance of a sample with rubber plates and samples coated with XYLAN.

The experimentally obtained temperature dependences of the elastic modulus and friction coefficients can be entered into the program windows for calculating seals using the finite element method [18-22].

5. Conclusion

As a result of experimental studies of the effect of temperature on the elastic modulus of rubber, it was found that for all types of rubber studied the elastic modulus begins to increase sharply with decreasing temperature from -20°C to -70 °C, and with increasing temperature from +20 to +100°C does not change. The temperature tests showed that all types of investigated rubbers are most sensitive to a decrease in temperature to negative values (-10°C) and an increase in deformation after cooling.

Studies of the friction coefficients of HNBR rubber for steel and XYLAN coatings of all types showed that when the temperature decreases from +20 to -40 °C, the friction coefficient increases 3÷4 times in the entire studied load range. An increase in temperature from +20 to +120°C does not cause a significant change in the coefficient of friction, especially at high loads. As the pressure on the friction surface increases from 0.8 MPa to 50 MPa, the friction coefficient for all XYLAN coatings decreases.

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