The study of application of Maslyanites in pumps designed for pumping aggressive media

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Abstract. For experimental studies, chemically active aggressive media pumped by single-screw metering pumps (SSMP) were used. The effect of these media on the destructive compressive stress, tensile strength, elongation, hardness, degree of swelling, antifriction properties and wear resistance of the polymer composite material Maslyanite D (S-1) was studied. It was established that hardness and antifriction properties of Maslyanite D (S-1) are better than those of SKN-26-based rubber 8470.

1. Introduction

Single-screw pumps are applied in the modern construction industry for pumping foam concrete, mortars, paints, adhesives, dibutyl phthalate, carbon tetrachloride, oleic acid nitrile and other aggressive media. The use of oil-petrol-resistant rubbers (grades 3626 and 6470) is limited due to their significant swelling in the aggressive media and irreversible physical and mechanical changes. When dosing media containing a high percentage of abrasive particles, there is a lot of wear of the clip and screw materials.

It is necessary to find and test materials with a low coefficient of friction, high wear resistance and good reciprocal compatibility with pumped fluids, which can be used both in the production and repair of single-screw metering pumps.

The impact of the working medium on polymers can decrease and increase their strength characteristics \cite{1}. The manifestation of this effect is determined by physicochemical properties of the medium and the polymer, the nature and value of the load application, its concentration, temperature and pressure, the ratio of fracture kinetics and diffusion of the medium \cite{2–4}.

2. Methods and materials

The study of strength characteristics of the oil group materials was carried out in carbon tetrachloride and dibutyl phthalate in an unstressed state of samples.
Carbon tetrachloride is one of the strongest solvents, and dibutyl phthalate has the greatest plasticizing effect [5].

Materials were tested in an unstressed state by the methods developed on the basis of GOST 4651-2014 (compression), GOST 11262-2017 (tension) and GOST 24622-91 (determination of hardness). [6–8]

Strength characteristics of the material were determined after every 170 hours in the media. The total test duration was 850 hours.

The measuring instrument, preparation techniques, and conditions were the same as in determining the degree of swelling of the materials. The tests were carried out using the UME-10 TM, providing load measurement with an error of not more than 1.0 % of the measured value.

Samples had a cylindric shape with a height of 15 ± 0.5 mm and a diameter of 10 ± 0.5 mm. 3–5 samples were placed in each medium; at least 5 samples were tested. Before the test, the dimensions of the samples were measured with an accuracy of 0.01 mm.

The breaking stress in compression was calculated using the known formulas.

Tensile samples had a shape of tongs (GOST 11262-76) and a smooth surface without cracks, shells and scratches. Before the tests, the thickness and width of that part of the sample that is tearing with an accuracy of 0.01 mm in at least 3 places were measured, and the cross-sectional area was determined. The sample was mounted in the clamps so that the direction of the tensile force coincided with the longitudinal axis of the sample.

The tests were carried out using the ALA-LLP at a gripping speed of 111 mm/h.

Hardness was determined using a hardness tester AS-III. A steel ball with a diameter of 5 mm was pressed into the test sample with an initially given force, which was increasing for 30 seconds. The duration of exposure to such a load was 60 seconds. Hardness measurements were made immediately after determining the degree of swelling.

3. Results

The test results (Figure 1) showed that a decrease in the breaking stress of compression of samples made from Maslyanite D (S-1) in carbon tetrachloride is 15.3–16.5 %; in dibutyl phthalate, a decrease in strength in all samples does not exceed 13.8 %.

A decrease in the tensile stress of Maslyanite D (S-1) with a prolonged exposure to carbon tetrachloride and dibutyl phthalate in the media is 27.1–31.7 % (Figure 2). Therefore, the material retains characteristics which are required for the media under study [3].

![Figure 1. Destructive compressive stress of Maslyanite D (C-1) depending on the exposure time in dibutyl phthalate (o) and carbon tetrachloride (x)](image-url)
Several compositions of Maslyanites D (S-1), K-15 and K-35 were tested. The relative elongation of the samples differs from each other (within 15 %). The test results are presented in Table 1 and Figure 3.

To determine the hardness of Maslyanite D (S-1) depending on the time spent in the media, the same samples were used. Hardness was measured immediately after determining the degree of swelling.

![Figure 2. Tensile strength of Maslyanite D (C-1) depending on the exposure time in carbon tetrachloride and (I) dibutyl phthalate (II)](image)

![Figure 3. Relative elongation at during the break of Maslyanite D (C-1) samples depending on the time spent in carbon tetrachloride (I) and dibutyl phthalate (II)](image)

Table 1. Relative elongation of samples from Maslyanite D (C-1) depending on the time spent in the media

| Medium | Relative elongation (%) depending on the time spent in the medium (h) |
|--------|---------------------------------------------------------------------|
|        | 0         | 170      | 340      | 510      | 680      | 850      |
| CCl4   | 5.5       | 5.5      | 53       | 5.2      | 4.8      | 4.1      |
| DBP    | 5.5       | 4.8      | 4.3      | 3.8      | 3.4      | 3.1      |
The surfaces did not have cracks, shells, or burrs; they were even, smooth, without visible treatment traces. For each test, 5 samples were used; 6 measurements were carried out on each sample. The value of hardness (HV) determined by the depth of indentation of the ball at a given basic force in kgf, was calculated by formula \[8\]

\[ HB = \frac{F \cdot 0.1}{\pi \cdot 0.5 \cdot h} \ (\text{MN/m}^2) \]

where \( F \) – value of the main indentation force, kgf;
0.5 – ball diameter, cm;
\( h \) – maximum indentation depth, cm;
0.1 – coefficient of hardness transfer from the GHS system to the ISS system.

As studies have shown (Table 2, Figure 4), the hardness of Maslyanite D (S-1) when it is in the carbon tetrachloride and dibutyl phthalate for a long time decreases by 20–25 %, which meets the requirements for the material working in these media for a long time.

| Medium    | Hardness of the material (MN/m²) depending on the time spent in the medium |
|-----------|--------------------------------------------------------------------------------|
| \( \text{CCl}_4 \) | 0.9 0.85 0.82 0.78 0.74 0.68 |
| DBP       | 0.9 0.86 0.83 0.80 0.77 0.69 |

By the degree of swelling and modification of physical and mechanical properties of the material depending on the time spent in the medium for a given period of time, it is possible to determine the performance of the material.

The main criterion for the performance of products made from polymer materials is the degree of swelling of the material in an unstressed state. However, studies [12] show that the degree of swelling of a polymer material depends on the applied load. Externally, mechanical loads and internal stresses can change the rate of diffusion penetration of the medium into the polymer, the nature of the effect of the medium itself, or accelerate or slow down the destruction of the material.

There are many methods used to assess strength properties of polymeric materials in contact with liquid media under the influence of static and dynamic loads. However, there are no standard methods for investigating the long-term strength of the fatigue properties of polymer materials working in liquid media [9, 10]. Therefore, to study the chemical resistance and change in the physicomechanical properties of Maslyanite D (S-1), a simple device was designed. Test samples were made in the form of a shovel according to GOST 11262-2017 and had the same parameters and technical requirements as for tensile test samples. The tests were carried out at 20 °C. Before the tests, the base length of the samples was measured, and the cross-sectional area was calculated. The weight of the sample was measured with an accuracy of 0.0001 g. The test sample was loaded into the medium, secured with screw clamps, and loaded through the block with a constant tensile load of 13 MPa (0.35σp).
This load was chosen on the basis of a five-fold margin of safety from the maximum pressure on the material under given operating modes of the screw pump. During testing, under the simultaneous influence of an external load and a liquid medium, the degree of swelling and a change in the linear dimensions of the samples were measured, and the strength properties of the material were evaluated.

When testing samples of Maslyanite D (C-1) in oleic acid nitrile (Tables 3 and 4), no significant effect on the change in the mass of the samples was found. The maximum deviation of the mass of the samples was only 0.15 %. The change in the length of the samples of Maslyanite D (S-1) which spent in the medium for 192 hours was only 0.15 %, and the length changed only in the first 100–120 hours, after which the sizes of the samples were stabilized. The tensile strength did not change, the deviation was within the accuracy of measuring the load by the UME-TM (1 %).

When the material is in the media for a long time, the swelling is insignificant, the residual strength is quite high when compared with stresses developed during the operation of a single-screw pump [11].

Table 3. Change in the mass of samples made from Maslyanite D (S-1) in oleic acid nitrile under tensile loading (%)

| No | Load, MPa | Exposure time, h | Note |
|----|-----------|------------------|------|
|    | 1         | 13               | 0.10 | 0.09 | 0.10 | 0.11 | 0.11 | 0.11 | 0.11 | Control samples |
|    | 2         | 13               | 0.10 | 0.09 | 0.10 | 0.12 | 0.12 | 0.12 | 0.12 | |
| 3  | –         | 0.08             | 0.06 | 0.06 | 0.07 | 0.07 | 0.07 | 0.07 | |

Table 4. Change in the length of samples made from Maslyanite D (S-1) in nitrile oleic acid under tensile loading (%)

| No | Load, MPa | Exposure time, h | Note |
|----|-----------|------------------|------|
|    | 1         | 13               | 0    | 0    | 0.07 | 0.14 | 0.14 | 0.14 |
|    | 2         | 13               | 0    | 0    | 0.07 | 0.15 | 0.15 | 0.15 | Control samples |
| 3  | –         | 0                | 0    | 0    | 0    | 0    | 0    | 0    |

The tests for compression, tension, hardness, and swelling allow us to conclude that high physical and mechanical properties of Maslyanite D (S-1) are preserved in the aggressive media.

Determination of tribotechnical characteristics (the wear rate and the friction coefficient of composite materials working in a friction pair) is an obligatory criterion for assessing their operational resource. [14] For this purpose, tests were carried out on rubber brand R-8470 and Maslyanite D (C-1) using the end friction machine at a speed of V = 0.2 m/s and pressure P = 0.5 MPa The counterbody material was steel 45.

Table 5. Tribological characteristics of composite materials

| Material               | Wear, g/h | Friction ration |
|------------------------|-----------|-----------------|
| Rubber R-8470          | 0.008     | 0.54            |
| Maslyanite D (S-1)     | 0.002     | 0.30            |

The test results (Table 5) showed that the wear of Maslyanite D (S-1) is significantly lower (4 times) that that of rubber R-8470. By the anti-friction properties, Maslaynite D (C-1) surpasses rubber by almost 2 times.

When testing in the abrasive medium, we obtained [13] positive results for many Maslyanite compositions.

4. Conclusion
Comparative tests of the physicomechanical and tribotechnical properties of the materials allows us to conclude that it is possible to use Maslyanite D (S-1) as clips for repairing single-screw metering pumps.
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