Effect of Climatic Aging on Tribological Performance of   
Two-Layer Rubber – UHMWPE Composite

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**Abstract.** In the severe conditions of the Far North, the impact of climatic aging of polymers on their properties is important due to long-term exposure to various environmental factors that lead to polymer degradation. The paper presents friction and wear tests using the ring-disk scheme, simulating a sealing unit, of a two-layer polymer composite rubber - ultra-high molecular weight polyethylene under various loads, sliding speeds and temperatures. The impact of climatic aging duration on the frictional behavior and wear resistance of the polymer composite was assessed. It was obtained that the friction coefficient depends on the sliding speed and load and decreases with increasing exposure time. The wear resistance of the material increases by 25% in the second month of aging and does not change over the next four. At elevated temperatures, the wear rate increases significantly, while at negative temperatures it does not change, relative to tests at room temperature. It can be concluded that the material can be used in friction units for a period limited by six months of climatic aging.

**Keywords:** climatic aging, rubber, UHMWPE, friction, wear

# INTRODUCTION

When modifying rubber sealing materials resistant to low temperature conditions of the Far North, the use of ultra-high molecular weight polyethylene (UHMWPE) is of considerable interest. Rubber seals of moving joints have highly elastic and damping properties, but have low wear resistance [1]. UHMWPE is suitable for use at low temperatures [2] and have good wear resistance and low coefficient of friction [3]. A composite combining these materials ensures the preservation of the useful characteristics of both materials [4].

As a result of prolonged exposure to low or high temperatures (and other environmental factors), the polymer properties change (ageing process) as a result of reactions, accompanied by destruction. In [5, 6] it is shown that UHMWPE is subject to this process, which will also affect friction. In [7] it is shown that when testing UHMWPE in a pair with steel according to pin-on-disk scheme, an increase in the sliding speed leads to an increase in the friction coefficient, and an increase in pressure leads to an insignificant decrease. In [8], based on an experiment on sliding of steel ball over UHMWPE disk and on modeling the process, it is demonstrated that crosslinking a thin layer of UHMWPE with rubber makes it possible to obtain a damping material with a low friction coefficient [9].

In addition, the application of polymer composite materials based on UHMWPE in oil and gas processing facilities under abrasive wear conditions is considered promising due to their high wear resistance and corrosion resistance properties [10, 11].

The aim of this study is to evaluate the influence of climatic aging on tribological properties of the rubber – UHMWPE composite under contact conditions simulating an end seal, at different sliding speeds, loads and external temperatures.

# MATERIALS AND METHODS

**Materials**

The two-layer polymer composite is 3.5 – 4 mm thick UHMWPE (GUR-4022, Celanese, China) coating on nitrile-butadiene rubber (NBR) substrate.

The rubber compound ingredients were mixed in laboratory rubber mixer Plastograph EC Plus (Brabender, Germany): 20 min, roller speed 25 rpm, 40 °C. The samples are made in a ring mold and have the following dimensions: outer and inner diameters are 54 and 40 mm, respectively, height 8 mm.

During production, preliminary pressing of UHMWPE powder is first carried out (10 MPa, 5 minutes), then the rubber compound is placed on top; the mold is closed, and further combined hot pressing is carried out in a thermohydraulic press (Impulse, Russia) at 155 °C, 20 minutes, 10 MPa.

**Methods**

**Aging.** Aging was made in climatic conditions typical for the city of Yakutsk, taking into account the impact of solar radiation, ambient temperature, air humidity, and other factors. The exposure took place on stands located at an angle of inclination to the horizon line of 45°, ensuring the orientation of the samples to the south, from April to September 2024, when atmospheric transparency and insolation were high. The average ambient temperature for the past exposure period was close to the average long-term temperatures (the minimum temperature was −3.6 °C, the maximum temperature was +20.4 °C).

**Friction and wear tests.** The friction experiment was carried out on a UMT-2 laboratory tribometer (Cetr, USA) using a kinematic scheme of unidirectional sliding of a ring on a stationary disk around their common axis of rotation. There was contact between the end surface of the ring (the material under study) and the plane of the disk (Ra ≥ 0.04 μm, AISI 304 steel) with a diameter of 65 mm and a thickness of 2 mm. During a single test with a constant load and speed, the sample rotated by 10 revolutions (friction path is 1.5 m). For a series of tests, a normal load was set and the sliding speed was varied: 0.1, 0.2, 0.4 and 0.6 m/s. The tests were carried out at the following normal loads: 50, 100, 200, 400 and 700 N (0.05 – 0.7 MPa). The test chamber was set at temperatures of -20, 23 (RT) and +60 ℃. Three tests were performed for each fixed combination of parameters (speed, load, temperature).

The study of abrasive wear resistance was carried out using the artificial base method with the following test parameters: load – 100 N, linear sliding speed – 0.1 m/s, friction path – 30 m. Sandpaper with a grain size of 250 μm was glued to the surface of the disk (counterbody). Rectangular depressions were applied along the radius of the samples (at an angle of 120 degrees relative to the ring axis). The wear rate indicator was the difference in the linear size, measured from the base to the rubbing surface, between tests, related to the friction path. The measurement was made after each test using a contactless optical profilometer.

**Non-contact profilometry.** The images of the sample surface with the corresponding roughness (ISO 25178) were obtained on an optical profilometer S Neox 3D (Sensofar, Spain). For this purpose we used 10X objective, confocal mode and automatic stitching of single frames into an area of needed size.

# RESULTS AND DISCUSSIONS

Climatic aging leads to a change in the mechanical properties of UHMWPE. After 2 months of exposure, the elastic-strength indicators improve by 20%, and after 6 months, UHMWPE completely loses its elasticity [8]. Figure 1 shows the effect of the specified duration of climatic aging on the friction coefficient depending on the speed at maximum and minimum loads in the experiment.

|  |  |
| --- | --- |
|  |  |
| *a* | *b* |

**FIGURE 1.** Influence of aging duration (solid – initial, dash – 2 months, dot – 6 months) on dependence of coefficient of friction COF on sliding speed V under load of 50 N *(a)* and 700 N *(b)*

As can be seen, for the initial material, increasing the load does not affect the friction coefficient. After aging, the material becomes sensitive to the load and also depends on the holding time. Under nominally conformal contact conditions, roughness increases the effective adhesive properties of the surface, which is most likely why the curves at a lower load lie higher than at a higher load. In general, the friction coefficient of the samples after aging is lower due to a decrease in surface energy and, accordingly, the adhesive component of the friction force. The effect of aging is also affect the surface topography of the samples during friction. Wear resistance can be indirectly estimated using data from Table I, which shows the parameters of typical surface roughness of the samples. With an increase in the aging duration, the difference between the surfaces before and after friction tests becomes smaller. For aged samples the starting roughness is greater than for initial ones; and final roughness after testing is smaller.

**TABLE 1.** Roughness before and after tests depending on aging duration

|  |  |  |
| --- | --- | --- |
| Time of aging, months | Roughness parameter Sq, μm | |
| before test | after test |
| initial | 0.38 | 1.11 |
| 2 | 0.53 | 0.92 |
| 6 | 0.54 | 0.62 |

Figure 2 shows the effect of temperature on the coefficient of friction when the composite is aged for 6 months. The effect of climate aging on wear was also analyzed (Table 2).

|  |  |  |
| --- | --- | --- |
|  |  |  |
| *a* | *b* | *c* |

**FIGURE 2.** Dependence of coefficient of friction (COF) on sliding speed (V) at negative *(a)*, room *(b)*, and elevated *(c)* temperatures for two-layer samples before aging (solid) and after aging (dash) under normal load of 50 N (square), 200 N (circle), and 700 N (triangle)

**TABLE 2.** Wear rate as a function of time of aging and test temperature

|  |  |  |
| --- | --- | --- |
| Time of aging, months | Test temperature, ℃ | Linear wear rate, μm/m |
| initial | RT | 1.5 ± 0.5 |
| 2 | RT | 1.1 ± 0.1 |
| 6 | RT | 1.1 ± 0.3 |
| 6 | –20 | 1.1 ± 0.03 |
| 6 | +60 | 1.6 ± 0.4 |

Despite the fact that UHMWPE aged for 6 months is destroyed by stretching, the rubber-UHMWPE composite samples retain their properties in friction contact at different temperatures. As noted above, the surface energy of the aged samples is lower, which explains the fact that the friction coefficient decreases after aging due to the correlation of adhesive forces with the surface energy. At negative temperatures, the dependences of the friction coefficient on the sliding speed differ from those at room and elevated temperatures. Apparently, UHMWPE does not exhibit rheological properties, and the dependence of the friction coefficient on speed is practically absent.

It can be noted that longer exposure to climatic aging due to increased polymer rigidity leads to a slight decrease in wear rate. The wear tests also show that wear increases with increasing temperature, and negative temperatures have no effect.

# CONCLUSION

As a result of atmospheric aging, the tribological properties of the rubber-UHMWPE composite (friction coefficient and wear resistance) are not lost. It is important to note that the less significant dependence of the friction coefficient on the speed for the aged material indicates a loss of its deformation properties, which can adversely affect the quality of the seals.

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