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Climate Tests of Composites Based on Ultrahigh Molecular Weight Polyethylene and Carbon Fibers

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Abstract. The article presents the results of climate tests of ultrahigh molecular weight polyethylene and a polymer composite material based on it. It is shown that the initial ultrahigh molecular weight polyethylene and a composite based on it undergo aging by the sixth month of exposure in the sharply continental climate of Yakutia. It has been established that ultrahigh molecular weight polyethylene and composites based on it must be modified not only with reinforcing fillers to increase physical-mechanical and tribotechnical parameters, but also with technological fillers that first of all, prevent the development of destructive-oxidative processes during operation in a sharply continental climate.

1. Introduction

Ultrahigh molecular weight polyethylene (UHMWPE) is known for its excellent wear-resistant and physical-mechanical characteristics. Polymer composite materials (PCM) based on it are used in many industrial fields. Low adhesive properties and the absence of hygroscopicity almost completely prevent rock from freezing on PCM surfaces at low temperatures. In this regard, the lining of containers and transport equipment is manufactured from PCMs based on UHMWPE to increase an intermaintenance period of bunkers, containers, conveyors [1-3].

It is known that structural and chemical transformations occur in polymers during prolonged exposure to low or high temperatures, as well as with temperature drops, freezing and thawing of moisture, and during the interaction of the material with the environment. In polymer matrices, the complex of these processes proceeds differently. In some polymers, structural changes occur rather quickly, and this may cause a reduction in the durability of their operation. In other materials, for example, in the ones with low chemical resistance, interaction with the medium can cause chemical transformations, which significantly affect the technical parameters. Climatic tests help not only to determine the current change in the properties of the material but also to predict the change in these properties in a certain future [4, 5, 6].

Therefore, climatic tests were conducted for a period of 12 months to determine the impact of various climatic and weather conditions on the physical-mechanical properties of ultrahigh molecular weight polyethylene and composite material based on it.



2. Research objects and methods

UHMWPE of Gur-4150 grade with a molecular weight of 9.2 million was used as the polymer matrix. Discrete carbon fibers (CF) of the Belum brand (OJSC Svetlogorsk Khimvolokno (Belarus) were used as filler. The specific gravity was $\approx 1.6 \text{ g/cm}^3$, and the fiber diameter was 7-10 microns.

Processing of UHMWPE and compositions based on it was performed using hot pressing technology at a pressure of 10 MPa and a temperature of 180 °C.

Experimental studies were conducted on samples of polymer materials and PCM in the form of extruded parts. The tensile strength, elongation at break, and the modulus of elasticity were determined according to GOST 11262-80 on UTS-20K testing machine.

The changes in the physical-chemical structure of PCM were studied by the infrared spectroscopy method. The IR spectra of PCM samples were recorded by the method of incomplete internal reflection on a Varian FTIR 7000 spectrometer in the frequency range of 400–4000 cm^{-1} . The identification and analysis of IR spectra were performed according to known methods using a spectrometer library and data on the IR spectra of polymers.

The study of changes in the basic properties of composites during natural aging under the climatic conditions characteristic of Yakutsk was accomplished according to GOST 9.066-76. Natural aging is accompanied by changing climatic conditions, which affect the polymer: natural ultraviolet radiation, precipitation, and partly ozone, temperature fluctuations, and other factors. The climate of the Republic of Sakha (Yakutia) is subarctic, sharply continental. The entire territory of the republic belongs to the regions of the Far North. The amplitude of average temperatures in January and July exceeds 75 degrees Celsius. Fig. 1 shows the maximum and minimum average daily temperatures by month (Fig. 1)

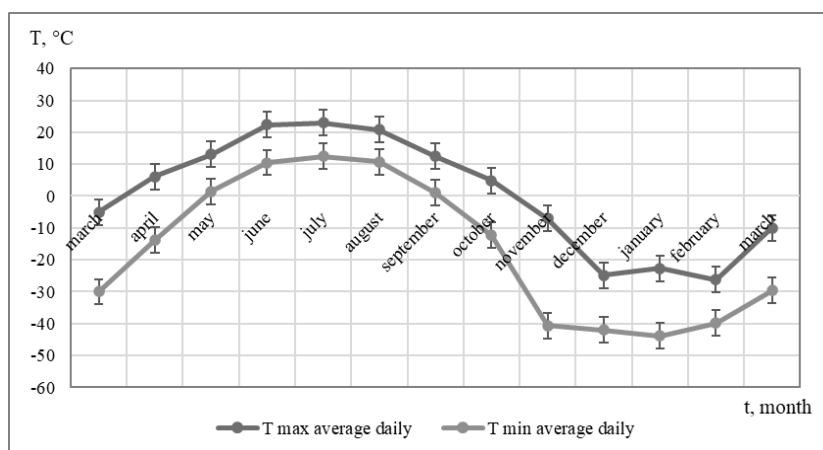


Figure 1. Maximum and average daily ambient temperatures by month.

3. Discussion of research results

In previous studies, it has been shown that the composite containing 5 wt.% of carbon fiber of the Belum brand has the optimal complex of operational characteristics [7]. Therefore, climatic tests were conducted on this composite material. Samples in the form of plates and columns were exposed to an open testing ground (Fig. 2) under natural atmospheric conditions in March 2018 in the city of Yakutsk RS (Ya). The changes in physical-mechanical properties of exposed samples were inspected after 1, 3, 6, 9, and 12 months.

It is known that the light, turns in the heating – cooling cycle, exposure to oxygen, ozone, and other factors accelerate aging. The principle of aging lies in a complex chain reaction that proceeds with the formation of free radicals (less often ions), which is accompanied by the destruction and structuring of the polymer. Usually, aging is the result of oxidation of the polymer with atmospheric oxygen. If destruction prevails, the polymer softens, and volatile substances are released. Brittleness increases during structuring, and loss of elasticity is observed [8].

The results of studies of the physical-mechanical properties of UHMWPE and a composite based on UHMWPE and CF subjected to full-scale exposure in the climatic conditions of Yakutsk are presented in Table. 1.



Figure 2. Exposed Samples.

Table 1. Physical-mechanical properties of UHMWPE and a composite based on it.

Exposure time	Exposed samples	ε_p (%)	σ_p (MPa)	E_m (MPa)
Initial (control) sample	UHMWPE	280	36.0	810
	UHMWPE + 5 wt.% CF	290	36.0	863
1 month	UHMWPE	380	43.4	750
	UHMWPE + 5 wt.% CF	318	36.1	904
3 months	UHMWPE	459	32.0	897
	UHMWPE + 5 wt.% CF	43	21.8	745
6 months	UHMWPE	13	25.4	1097
	UHMWPE + 5 wt.% CF	39	21.8	-
9 months	UHMWPE	7.7	20.8	-
	UHMWPE + 5 wt.% CF	75.3	23.5	-
12 months	UHMWPE	6.5	20.4	-
	UHMWPE + 5 wt.% CF	77	20.6	867

It was found that the stress-strain properties of the initial UHMWPE and composites increase after exposure for 1 month in comparison with the properties of the initial samples. An increase in relative elongation by 25% and in strength by 20% was recorded in the case of unmodified UHMWPE. The relative elongation of PCM increased by 10% while maintaining strength at the level of the initial (control) sample.

It has been shown that the relative elongation of unmodified UHMWPE increases by 1.6 times after exposure for 3 months. The elasticity of UHMWPE drops sharply to 22 times after 6 months of exposure

in the open air compared with the original polymer. During the tensile test, brittle fracture is detected on samples exposed for 6, 9, and 12 months. A monotonic decrease in tensile strength is observed throughout the exposure. The strength of the sample exposed for 12 months deteriorated 1.8 times. Thus, it was shown that in the subarctic climate of RS (Y), UHMWPE samples and composites based on it and modified with CF undergo aging, which is followed by a change in their molecular structure, leading to loss of elasticity, lower strength, increased rigidity, and brittleness [9].

IR spectroscopic studies (Fig. 3) of the initial UHMWPE and the exposed polymer materials were conducted to study the structural changes.

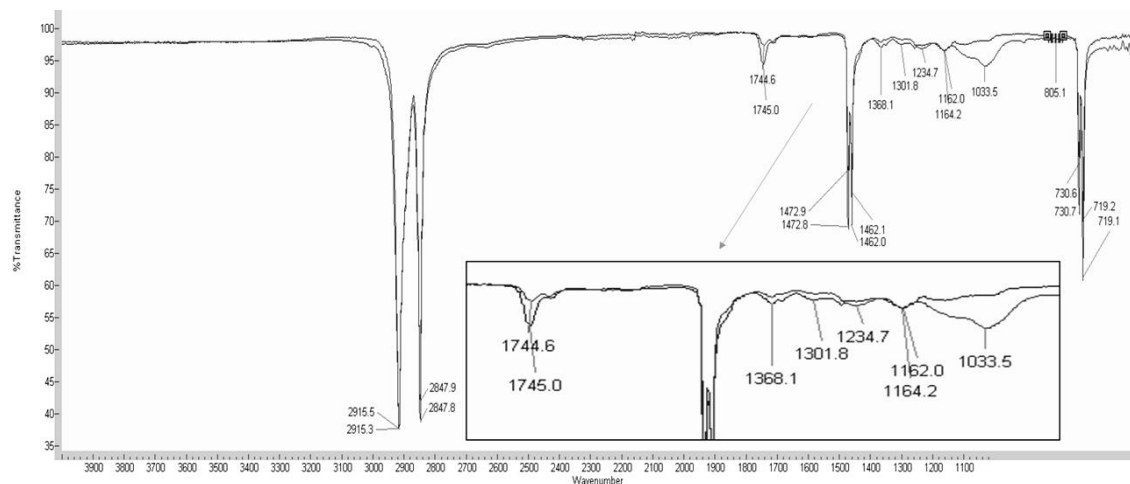


Figure 3. IR spectra of the initial UHMWPE and UHMWPE exposed for 6 months.

Doublets (2915 cm^{-1} and 2848 cm^{-1}), responsible for the symmetric and asymmetric valence vibrations of C-H, as well as a doublet, responsible for deformation vibrations of C-H (1464 cm^{-1}), and crystallinity bands were detected (719 cm^{-1}) in the IR spectra (Fig. 3).

It was found that medium-intensity peaks appear on the surface of the sample exposed in the air in the areas $\sim 1745 \text{ cm}^{-1}$, 1368 cm^{-1} , 1234 cm^{-1} , 1030 cm^{-1} , 805 cm^{-1} , which indicates the absorption of oxygen by the surface, leading to the formation of carbonyl, carboxyl, and hydroxyl groups. Oxidation of the polymer leads to a change in its physical structure and a deterioration in mechanical properties. The oxidation processes in the surface layer of UHMWPE and its composites occur since the RS (Y) climate is distinguished not only by low temperatures and sharp daily drops in the autumn and spring periods but also by the high intensity of solar radiation and an increased concentration of ozone in the atmosphere.

Table 2 presents the thermodynamic characteristics of the PCM depending on the exposure time.

Table 2. Thermodynamic characteristics of PCM.

	Melt Onset Temperature ($^{\circ}\text{C}$)	Melt Peak Temperature ($^{\circ}\text{C}$)	Melt Offset Temperature ($^{\circ}\text{C}$)	Enthalpy (J/g)	Crystallinity (%)
UHMWPE + 5 wt.% CF (control sample)	125.4	138.7	146.0	135.4	46.2
UHMWPE + 5 wt.% CF, exposed 1 month	126.5	139.7	147.0	138.6	47.3
UHMWPE + 5 wt.% CF, exposed 6 months	127.9	140.6	148.6	150.3	51.3

A monotonic increase was established in all thermodynamic parameters depending on the exposure time. The work [10] describes a method for estimating the polymer service life based on measurements of melting enthalpy during their aging. The melting enthalpy of the composite exposed for 6 months exceeds the characteristics of the starting material by 11%, which indirectly indicates the destruction of the material. This is consistent with the results of testing the mechanical characteristics.

4. Conclusion

It has been established that ultrahigh molecular weight polyethylene and a composite based on it and modified with carbon fiber ages by the sixth month of exposure. The aging process of UHMWPE and composites with Belum carbon fibers is followed by a decrease in mechanical characteristics, embrittlement, an increase in thermodynamic parameters, and an oxidative degradation processes in the surface layer of the material. The oxidative degradation of the samples is confirmed by the appearance of peaks on the surface of the exposed sample, indicating the absorption of oxygen by the surface.

Thus, it is critical not only to modify ultrahigh molecular weight polyethylene and composites based on it with reinforcing fillers to increase physical-mechanical and tribotechnical parameters but also to use technological additives. These additives are necessary, first of all, to prevent or inhibit the development of destructive-oxidative processes in polymer materials when used outdoors in the climatic conditions of the Republic of Sakha (Yakutia).

5. References

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