ABSTRACT

of the dissertation for the degree of Doctor of Philosophy (PhD) in the educational program 8D05301 – «Physics»

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Effect of diabase - mineral filler on structure and physical and mechanical properties of ultra-high molecular weight polyethylene.

General characterisation of the work. The dissertation work is devoted to the study of structure and physicomechanical properties of UHMWPE coatings with mineral diabase filler. The main regularities of the influence of diabase-mineral filler on the structure and physicomechanical properties of UHMWPE are established.

Relevance of the research topic.

Polymer composite materials are widely used in modern engineering, including machine-building, transport, processing and mining industries. Among polymeric materials ultra-high molecular weight polyethylene (UHMWPE) occupies a special place due to its unique combination of practical important properties. Additional prospects for its use in various branches of mechanical engineering are represented by the introduction of various fillers, including mineral fillers, which makes it possible to significantly increase mechanical and tribological properties of composite materials based on it.

However, as follows from the literature analysis, an important aspect of the research is to determine the relationship between the formed structure of composites based on UHMWPE and the properties provided by it. In this regard, it seems very relevant to investigate the influence of different mineral fillers on the structure and properties of UHMWPE.

The relevance of the work is also confirmed by the implementation of research in the framework of the following projects: the project of fundamental research of the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan IRN № AP09259925 «Development and implementation of high-efficiency technology of anticorrosive coating on the basis of ultra-high molecular weight polyethylene» (2021-2023 years) and IRN № AP19679461 «Development and implementation of radiation- and corrosion-resistant protective composite material on the basis of ultra-high molecular weight polyethylene with fillers».

Research in the field of coatings based on UHMWPE and its composites is quite active and is presented on the pages of leading peer-reviewed scientific journals. It should be noted the works of various authors, including Mohammed Abdul Samad, Jing Han, S.M. Kurtz, V. Saikko, K.G. Plumlee, C.J. Schwartz, S.V. Panin, A.A. Okhlopkova, M.D. Sokolova, S.D. Kaloshkin, V.O. Aleksenko and many others.

Thus, R.M. Kumar, Jiongrun Chen, Wenying Zhou, M. Naffakh, G. Wang, K. Yang investigated the effect of functionalisation of mineral fillers from the position of possible increase in mechanical properties of polymer composites. Jing Han et al.

investigated the effect of graphene nanoplatelet (GNP) on the structure and properties of UHMWPE coating. The structure of UHMWPE remained almost unchanged after sputtering treatment, and the addition of GNPs resulted in a slight decrease in crystallinity and improved thermal stability of UHMWPE. In addition, the coating containing 1.0 wt% of HNP showed a ~20% reduction in wear rate and a 25% reduction in coefficient of friction. The significantly improved corrosion behaviour of the UHMWPE+HNP coatings was confirmed by the increase in corrosion potential, corrosion current density and impedance modulus of the UHMWPE+ GNP coatings.

S.V. Panin studied the reinforcement of UHMWPE matrix with basalt particles. They found that in dry sliding friction: wear resistance of composites increases 3 times with the addition of 20 wt% of filler. The addition of basalt fibres to UHMWPE provides an increase in abrasive wear resistance, which increases by 2.5 times when the mass fraction of filler is varied in the range of 10-20 wt%.

Based on the analysis of the results of previous works, the idea of improving the physical and mechanical properties of UHMWPE by introducing mineral filler particles arose. It is assumed that the introduction of mineral filler in the form of diabase into the composition of UHMWPE will contribute to the formation of an optimised structure of the coating, which will lead to the improvement of its physical-mechanical, tribological and corrosion properties.

It should be noted that diabase, as a mineral raw material close to basalt, has good mechanical properties and chemical resistance to aggressive media, affordable cost and environmental friendliness. Diabase is a volcanic igneous rock, the main component of which is well-preserved plagioclase, colourless and transparent, rarely occurring pyroxene. The melting point is 1005-1250°C.

However, in our opinion, the influence of the filler in the form of diabase on the structure and properties of UHMWPE-based composites has not yet been studied. For this reason, it is of considerable scientific and practical interest to conduct systematic studies of the influence of diabase - mineral filler on the structure of UHMWPE and on its mechanical, tribological and corrosion properties.

The aim of the dissertation work is to establish the regularities of influence of mineral filler in the form of diabase on the structure and physical-mechanical and corrosion properties of UHMWPE.

In order to achieve the set goal the following **main tasks** are solved in the work:

- to study the changes in the structure of UHMWPE coatings as a result of the introduction of diabase filler and to establish the mechanisms of the filler influence;
- to determine the influence of diabase-filler of different composition on the physical and mechanical properties of UHMWPE coatings;
- to carry out experimental studies of corrosion resistance of UHMWPE-based composite coatings in aggressive media;
- to substantiate the applied potential of composite coatings based on UHMWPE with a mineral diabase filler based on experimental data, confirming their practical significance with a patent and implementation acts.

The main points put forward for defence:

1. Modified UHMWPE-based coatings obtained by gas-flame spraying with the participation of mineral filler diabase form a heterogeneous structure of amorphous and crystalline phases. Increase of diabase concentration up to 10-40 wt.% increases internal stresses in amorphous matrix and limits mobility of polymer chains. This phenomenon slows down the growth kinetics of crystals and leads to a decrease in their size.

2. The introduction of the mineral filler diabase significantly improves the physical and mechanical properties of UHMWPE-based composite coatings. Diabase particles, being located in the amorphous matrix, promote the growth of internal stresses and restrict the movement of macromolecules, which increases the structural strength of the coating. As a result, the microhardness of the composite coatings increases from 5.34 to 7.27 Hv, the coefficient of friction decreases from 0.17 to 0.05, and the wear resistance increases more than twofold compared to the original UHMWPE.

3. The influence of aggressive medium on corrosion resistance of UHMWPE coatings and composites with mineral filler has been revealed. Reducing the amount of diabase from 40 to 10 wt.% increases the corrosion resistance of the coating (from 0.058 g to 0.02119 g), which is associated with an increase in the proportion of the crystalline component in the polymer matrix and the slowing down of diffusion processes. In addition, the optimal amount of diabase promotes the formation of a dense and homogeneous protective layer on the coating surface, which limits degradation processes under the influence of aggressive media. This increases the service life of composites and increases their operational reliability.

The scientific novelty of the work consists in the following:

1 For the first time the regularities of the influence of diabase mineral filler on the structural-phase state of composite coatings based on UHMWPE obtained by gas-flame spraying have been established. The introduction of diabase in the composition of UHMWPE with the content of 10-40% of the total mass does not significantly affect the degree of crystallinity of the coating and its chemical structure.

2 The role of diabase-mineral filler in the improvement of physical and mechanical properties of UHMWPE-based composite coatings has been revealed and quantitatively evaluated for the first time. Improvement of physical and mechanical properties of UHMWPE-based composite coatings with mineral diabase filler. The content of mineral diabase filler plays a significant role in improving the mechanical properties of UHMWPE-based composites. So, microhardness for pure UHMWPE coating is 5,34 Hv; for 10 wt.% UHMWPE+Diabase coating is 5,67 Hv; for 20 and 30 wt.% UHMWPE+Diabase coating is 6,15 Hv and 6,95 Hv; respectively for 40 wt.% UHMWPE+Diabase coating is 7,27 Hv. The wear resistance of UHMWPE-based composites with the addition of n wt.% diabase increases as the matrix is filled. Thus, with increasing the filler content up to 40 wt.%, the wear resistance increases more than 2 times compared to pure UHMWPE, and the roughness increases from 1.237 to 4.311

μm. The addition of diabase leads to a noticeable decrease in the coating friction coefficient: for pure UHMWPE coating ~ 0.17; UHMWPE+Diabase 10 wt.% ~ 0.14; UHMWPE+Diabase 20 wt.% ~ 0.09; UHMWPE+Diabase 30 wt.%, 0.06; and for UHMWPE+Diabase 40 wt.% ~ 0.05.

3 The resistance of composites based on UHMWPE with diabase - mineral filler to aggressive media has been revealed for the first time. Samples from pure UHMWPE and UHMWPE composite with 10 % of diabase content have the best chemical resistance to acid medium. After chemical influence the crystallinity of pure UHMWPE coating decreases by 22 %, and that of UHMWPE composite with 10 % diabase-mineral filler by 18 %.

Study Subject.

Composite coatings based on UHMWPE with diabase-mineral filler, structure and physical and mechanical properties of composite coatings.

Object of research.

Change of microstructure and physical and mechanical properties of coatings based on UHMWPE with mineral-diabase filler. Determination of corrosion resistance of coatings obtained by gas-flame coating method.

Methods of research and testing.

To analyse the macro- and microstructure and phase composition of the samples under study we used general scientific methods of metallographic research with the use of scanning electron microscopy and X-ray structural analysis. To determine the elemental and phase composition of the samples X-ray microanalysis and infrared spectroscopy methods were used. Determination of mechanical, tribological and corrosion properties was carried out on devices and stands using certified methods.

Scientific and practical significance of the work.

The obtained results allow to understand the physical and mechanical properties of UHMWPE at interaction with mineral diabase filler.

The results of the research presented in the thesis work are implemented in production for use in future projects of «PlasmaScience» LLP. In addition, they are implemented in the educational process and used in diploma works in the training of students on the following educational programmes: 6B05305 – «Applied Physics, Nanomaterials and Innovation», 6B05303 – «Nuclear Physics and Atomic Energy», 7M05301 – «Physics», 8D05301 – «Physics». The relevant materials are given in the appendices to the thesis work.

Patent No. 8197 for useful model «Powder material for gas-thermal spraying of polymer coatings' RSE 'National Institute of Intellectual Property» MJ RK, official bulletin No. 2023-06-23 was received.

The dissertation work was carried out in the scientific departments of the National Scientific Laboratory of Collective Use (Technopark «Shygys Bastau») and the Research Centre «Surface Engineering and Tribology» of the East Kazakhstan University named after Sarsen Amanzholov (Ust-Kamenogorsk, Kazakhstan), as well as in Nazarbayev University and in the Department of Experimental Physics of the

Engineering School of Nuclear Technologies of the National Research Tomsk Polytechnic University (Tomsk, Russia).

Author's personal contribution. The author's personal contribution consists in the search and analysis of literary periodicals devoted to the topic of the thesis research, in particular, gas-flame coatings based on UHMWPE. Together with the scientific advisors determined the goals and objectives of the research, selected deposition methods and methods of research of composite coatings. The author of the thesis was directly involved in the preparation of samples, studied the phase composition, surface morphology of the obtained coatings, measured the microhardness and wear resistance of the coatings, investigated the influence of aggressive, acidic environment on the microstructure and corrosion resistance of the coatings, and was directly involved in analysing the results and writing articles together with consultants and laboratory specialists.

Relation of the topic to the plans of research programmes

Experimental results of the present dissertation work were obtained with the financial support of the State Institution Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan under the following themes: 1) «Development and implementation of highly effective technology of anticorrosion coating on the basis of ultra-high molecular weight polyethylene», 2021-2023, IRN №AP09259925; 2) «Development and implementation of radiation- and corrosion-resistant protective composite material on the basis of ultra-high molecular weight polyethylene with fillers» 2022-2025, IRN №AP19679461.

The results of the research correspond to the goals and objectives of polymer physics and are aimed at solving urgent problems in the field of condensed state physics.

Practical value of the work. On the basis of the research results a scientifically substantiated method of obtaining protective coatings on the basis of UHMWPE with mineral filler diabase, providing an increase in wear and corrosion resistance of materials. Composite coatings obtained by gas-flame spraying method effectively protect metal surfaces operating in aggressive chemical environments, which expands the possibilities of their industrial application. On the basis of the obtained data a useful model of powder mixture has been developed and patented, and a technological solution has been implemented in production conditions, the efficiency of which has been confirmed by industrial tests. The results of the research have been implemented in the educational process and contribute to the improvement of the quality of training of future specialists.

The degree of validity and reliability of the results obtained in the work is ensured by the correctness and systematicity of the conducted experimental studies, as well as by the use of well-proven general scientific research methods. The main results of the dissertation were published in the editions recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Education and Science of the Republic of Kazakhstan for the publication of the results of scientific

activity, as well as in a peer-reviewed foreign scientific journal, included in the database Scopus and Wep of Science.

Approbation of dissertation work. Materials of the dissertation work were reported and discussed at domestic and international scientific conferences:

1. 2nd International Conference on «Functional Materials and Chemical Engineering» (04-05, April, 2022, South Corolina, USA);
2. XVIII International Scientific and Practical Conference on «New Polymer Composite Materials» Mikitaev Readings (4-9 July, 2022, Elbrus, KBR, Russia)
3. International scientific-practical conference «Uvaliev Readings-2022» «Actual problems of science and education in the conditions of modern challenges», dedicated to the 70th anniversary of S. Amanzholov VCU
4. International Conference «Actual Problems of Modern Physics» Abdildin Readings Al Farabi Kazakh National University (12 - 15 April 2023) Almaty, Kazakhstan;
5. XV International Scientific and Technical Conference on «New Materials and Technologies: Powder Metallurgy, Composite Materials, Protective Coatings, Welding». Institute of Powder Metallurgy named after Academician O.V.Roman. (14-16 September, 2022. Minsk, Belarus).
6. X International Scientific and Practical Conference on «Integration of Education-Science-Business: Problems and Prospects» East Kazakhstan University named after S. Amanzholov. S. Amanzholov, April, 2024, Ust-Kamenogorsk;
7. X International scientific and technical conference on the theme «Creativity of young people - innovative development of Kazakhstan» East Kazakhstan Technical University named after S. Amanzholov, April, 2024, Ust-Kamenogorsk; 7. D. Serikbayev, 11-12 April, 2024, Ust-Kamenogorsk.

The main results were reported and discussed at the joint scientific seminars of S. Amanzholov East Kazakhstan University, scientific seminars of D. Serikbayev East Kazakhstan University and the meeting of the Department of Experimental Physics of the Engineering School of Nuclear Technologies of the National Research Tomsk Polytechnic University.

Publications

By results of the researches stated in the dissertation 13 printed works are published, from them in peer-reviewed scientific editions of RK recommended by Committee on quality assurance in the sphere of science and higher education of MNVO RK - 3, in the journal indexed in databases Scopus and Web of Science - 2, and also 8 articles in collections of materials of international conferences, including 3 in collections of materials of foreign international conferences.

Structure and volume of the dissertation work. The dissertation consists of an introduction, four chapters, conclusion and list of used literature, a total of 121 pages, 67 figures, 19 tables, 145 list of used literature, 3 appendices.