ISSN 2079-1372 Problems of Tribology, V. 30, No 4/118-2025, 37-41

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2025-118-4-37-41

The influence of high-entropy alloys on the abrasive wear index of ultra-high-molecular-weight polyethylene

A.-M.V. Tomina[1] 0000-0001-5354-0674, **V.Yu. Shurpik**[1] 0009-0002-8007-8088, **Ye.A. Yeriomina**[1] 0000-0001-8595-5735, **Predrag Dašić**[2] 0000-0002-9242-274X, **V.B. Burzaiev**[1] 0009-0000-6725-4003

[1]*Dniprovsk State Technical University, Kamyanske, Ukraine*
[2]*Academy of Professional Studies Šumadija – Department in Trstenik, Trstenik, Serbia*
E-mail: an.mtomina@gmail.com

Received: 10 October 2025: Revised 30 October 2025: Accept: 15 November 2025

Abstract

This work examines the influence of high-entropy alloys $Fe_{20}Ni_{20}Co_{20}Be_{20}Si_{14}B_6$ and : $Al_{40}Co_{12}Cu_{12}Cr_{12}Ni_{12}Fe_{12}$ on the abrasive wear index of ultrahigh-molecular-weight polyethylene. The effective filler content that ensures the minimum wear rate has been determined. For the $Fe_{20}Ni_{20}Co_{20}Be_{20}Si_{14}B_6$ alloy, the optimal concentration is 25 wt.%, whereas for the: $Al_{40}Co_{12}Cu_{12}Cr_{12}Ni_{12}Fe_{12}$ alloy it is 20 wt.%. The overall improvement in abrasive resistance reaches 35–45% compared to unfilled polyethylene. The enhancement in wear resistance is attributed to the strengthening of the polymer matrix by hard particles of the high-entropy alloys, whose microhardness exceeds 10000 MPa. Their introduction significantly increases the material's ability to resist mechanical degradation of the surface layers during friction against rigidly fixed abrasive particles. The obtained results confirm the feasibility of using high-entropy alloys as effective functional fillers for the development of wear-resistant polymer composites based on ultra-high-molecular-weight polyethylene and open up promising directions for further research in this field.

Keywords: ultra-high-molecular-weight polyethylene, abrasive wear index, high-entropy alloy, polymer composite material

Introduction

A major part of modern industrial equipment in Ukraine and around the world operates in conditions of severe abrasive wear. As a result, enterprises incur significant economic losses due to their downtime and repair. This problem is especially acute in the mining, automotive, and agricultural industries, where equipment operates in environments saturated with solid abrasive particles: sand, mineral inclusions, and rocks. An effective solution to this problem is introducing new wear-resistant polymer composite materials (PCMs) based on thermoplastic polymers containing dispersed metal filler (Fl). Such materials combine high strength, resistance to wear, corrosion and many chemical reagents with low density and technological ease of forming products, particularly, parts of complex geometry. Due to this, these composites are characterised by high functional properties, therefore they are an excellent alternative to traditional metals and alloys operating in conditions of intense abrasive wear. As the analysis of literary sources [1-3] has shown, using such materials instead of traditional ones (bronzes of the BrAZh brand, aluminium alloys, Gr3 and Gr2D2.5 cermets) allows for an increase in the durability of high-performance equipment by six times. Among the large number of polymer materials, we can distinguish ultra-high-molecular-weight polyethylene (UHMWPE), which is one of the most widely used technical polymers today. Composites based on it, including those containing dispersed Fl (in particular, liquid-quenched binary alloys of the Al-Ni, Al-Cr, Al-Co system, hydrogenated diamond-like carbon, metal oxides and sulfides, and graphite), are characterised by a combination of high functional properties, especially increased wear resistance, chemical inertness, and resistance to shock loads [4-7]. Given the above, searching for new compositions of composites based on UHMWPE is a relevant and promising task aimed at expanding the possibilities of their use in conditions of intensive wear in the mining, automotive, and agricultural industries.

Copyright © 2025 A.-M.V. Tomina, V.Yu. Shurpik, Ye.A. Yeriomina, Predrag Dašić, V.B. Burzaiev. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The purpose of the work

Considering the above, the aim of this work is to investigate the influence of the percentage content of dispersed fillers–high-entropy alloys on the abrasive wear index of UHMWPE under conditions of rigidly fixed abrasive particles.

Objects and methods of research

UHMWPE (manufactured by Jiujiang Zhongke Xinxing New Material Co., Ltd., China) was used as a polymer matrix to create new wear-resistant PCMs [6].

Two high-entropy alloys (HEAs) were chosen as dispersed Fls for UHMWPE: $Al_{40}Co_{12}Cu_{12}Cr_{12}Ni_{12}Fe_{12}$ and $Fe_{20}Ni_{20}Co_{20}Be_{20}Si_{14}B_6$. These alloys usually contain from 5 to 13 elements in equiatomic or close to equiatomic concentrations. High-entropy (multicomponent) alloys are currently attracting considerable attention from researchers due to several improved physical and operational properties, including high corrosion resistance. Five or more components in the alloy in an equiatomic ratio ensure high entropy of the alloys. The difference in the atomic radii of the elements gives the crystal lattice a very high level of stresses (partly microstresses), which provides a high level of hardness and wear resistance. A certain ratio of elements leads to the formation of alloys with bcc, fcc or a mixture of crystal lattices. It is known [8] that bcc and fcc lattices are characterised by a different number of slip planes: it is the largest in the fcc lattice. Due to this, the hardness of the HEAs with the bcc lattice is the largest with relatively low plasticity, and vice versa. Therefore, in some cases, it is useful to obtain alloys with a mixture of bcc and fcc lattices, which allows combining relatively high hardness and plastic characteristics in the HEAs. It should be noted that obtaining structures close to the microcrystalline state is possible because of the significant difference in atomic radii. This can be traced by broad diffraction lines. As it is known, such a state provides a high level of corrosion resistance. It is worth noting that the recorded high level of microstresses can exceed $2{,}7\cdot10^{-3}$, which provides microhardness over HV=10000 MPa. Positive prospects are based on the fact that an amorphous structure, which will naturally combine high physical, tribological, and corrosion-resistant properties, may form in the structure of the HEAs during quenching from the melt. Currently, HEAs are receiving significant attention worldwide because of the possibility of using various elements in their equiatomic amount, as well as due to the prospects for implementing HEAs and developing the latest technologies [9]. Creating products and studying the abrasive wear index of new wear-resistant PCMs based on ultra-high-molecular-weight polyethylene was performed according to the method given in [6], which includes the activation of the HEAs in the magnetic field of a vortex mixer. The study of the roughness (R_a scale, μm) and the morphology of the friction surfaces of pure UHMWPE and PCMs based on it was done using a 170621 probe profilometer and a BIOLOM-M microscope. The hardness of the PCMs was measured on the Rockwell scale (HRR, hardness units) using a 2074 TPR device [9].

Results analysis and discussion

Evaluating the results of tribological properties (Fig. 1) of dispersion-strengthened PCMs shows that using high-entropy alloys (at.%) $Al_{40}Co_{12}Cu_{12}Cr_{12}Ni_{12}Fe_{12}$ (alloy №1) and $Fe_{20}Ni_{20}Co_{20}Be_{20}Si_{14}B_6$ (alloy №2) as Fls is an effective way to reduce the abrasive wear index of ultra-high-molecular-weight polyethylene by 30–45%

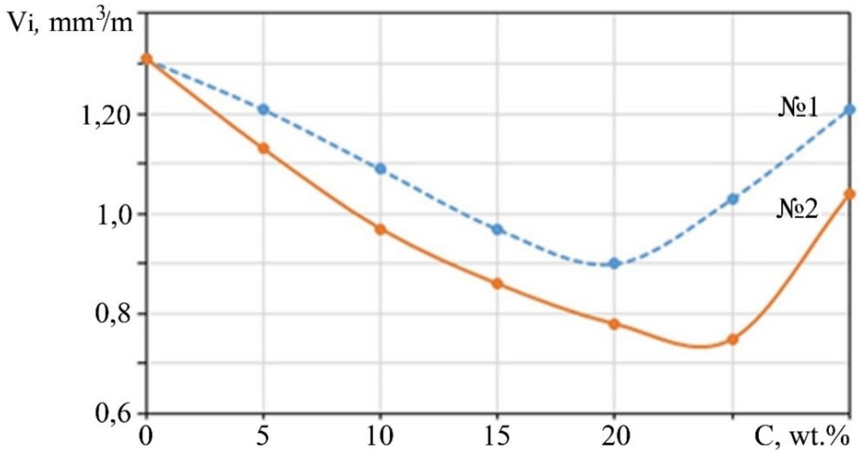


Fig. 1. The influence of the percentage content (C, wt.%) of HE alloys 1 and №2 on the abrasive wear index (V_i, mm^3/m) of UHMWPE

The increase in wear resistance of UHMWPE to the action of abrasive particles is because dispersion-reinforced PCM fillers acquire high strength and resistance to mechanical damage. This occurs because there is a mixture of fcc and bcc lattices in the structure of HEAs, which provides a high level of microstresses (≥2.7 10^{-3}) and microhardness (~10000 MPa). The established increase in PCM hardness by 1.6 g. (Fig. 2), a decrease in PCM roughness by 45% (see Fig. 3), and a comparison of friction surfaces confirm this. Fig. 4 shows that deep ploughing of UHMWPE is observable on the friction surface of UHMWPE, while the PCM surfaces are more uniform and homogeneous [10], which indicates an increase in wear resistance [11].

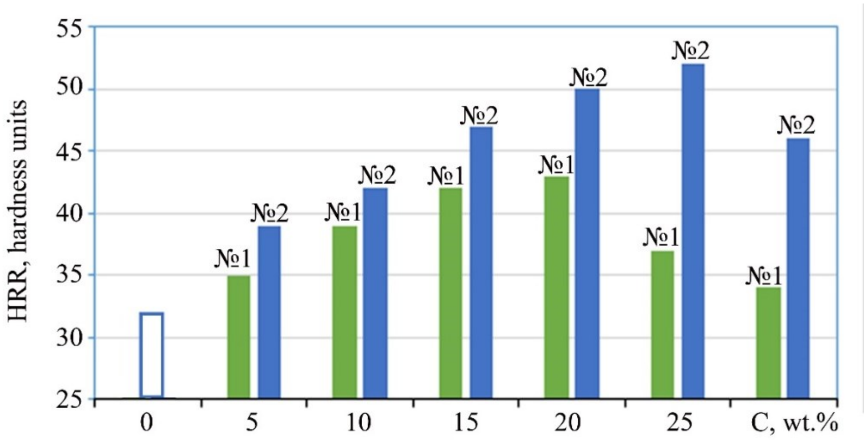


Fig. 2. The influence of percentage content (C, wt.%) of HE alloys №1 and №2 on hardness (HRR, hardness units) of UHMWPE

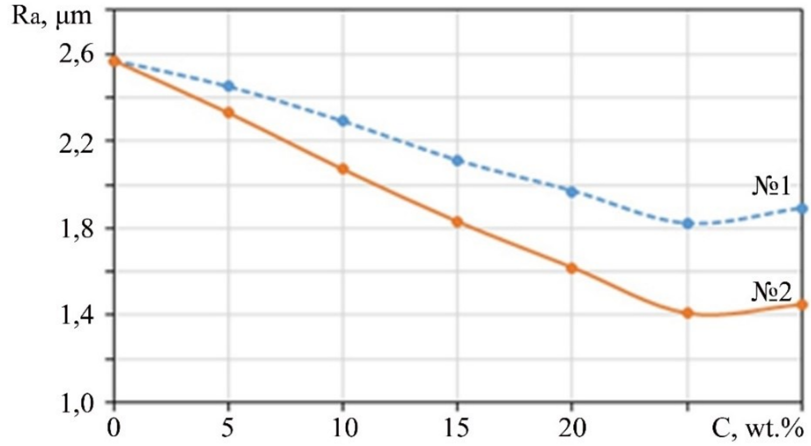


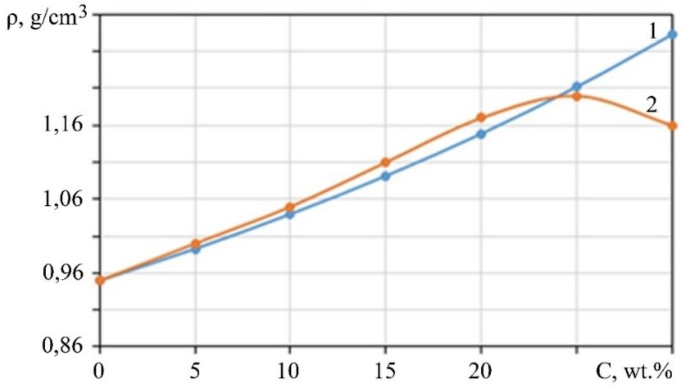
Fig. 3. The influence of the percentage content (C, wt.%) of high-entropy alloys №1 and №2 on the roughness (R_a, μm) of UHMWPE

a b c

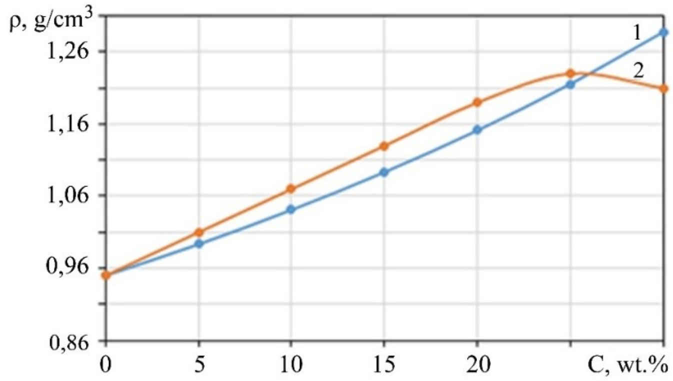
Fig.4. Friction surfaces (×200) of UHMWPE (a) and composites based on it containing 20 wt.% of alloy №1 (b) and 25 wt.% of alloy №2 (c)

It should be noted that with an increase in the percentage of alloy №1 and №2 in the UHMWPE to 25–30 wt.% and 30 wt.%, respectively, a decrease in the abrasive wear resistance of the developed PCMs is observed. This is probably a consequence of the increased defects in the material: the formation of voids, pores, and microcracks. A comparison of the experimental (1) and theoretical (2) densities of the developed PCMs (Fig. 5) can confirm this conclusion [11].

The dependences in Fig. 4 clearly show that when the content in the PCMs is 5–20 wt.% of alloy №1 and 5–25 wt.% of alloy №2, the experimental density of the PCMs is somewhat higher than the theoretical one. This indicates a more ordered supramolecular structure of the developed PCMs because of the strong intercomponent interaction at the "UHMWPE-high-entropy alloy" interface. With a further increase in the amount of HEAs in the volume of the UHMWPE, an inverse ratio is observed. This can be explained by the fact that the HEA particles of alloys №1 and №2 find it difficult to achieve uniform distribution in the volume of UHMWPE as a result of the strong intermolecular energy of their components (E(Fe)=$4.04\cdot10^5$ J/mol, E(Al)=$3.11\cdot10^5$ J/mol, E(Co)=$4.39\cdot10^5$ J/mol, E(Cu)=$3.39\cdot10^5$ J/mol and E(Ni)=$4.22\cdot10^5$ J/mol) [12].



a



b

Fig. 5. Dependence of theoretical (1) and experimental (2) density (ρ, g/cm^3) of UHMWPE on the percentage content (C, wt. %) of high-entropy alloys №1 (a) and №2 (b)

Subsequently, the filler particles stick together, forming agglomerates (clusters) with a smaller contact surface with UHMWPE.

Conclusions

Analysis of the results of the conducted research showed that using high-entropy (multicomponent) alloys $Fe_{20}Ni_{20}Co_{20}Be_{20}Si_{14}B_6$ and $Al_{40}Co_{12}Cu_{12}Cr_{12}Ni_{12}Fe_{12}$ as Fls for UHMWPE is an effective way to improve its tribological properties by reducing the abrasive wear and roughness index by 45%. We established that the effective Fl content is 25 wt.% $Fe_{20}Ni_{20}Co_{20}Be_{20}Si_{14}B_6$ and 20 wt.% $Al_{40}Co_{12}Cu_{12}Cr_{12}Ni_{12}Fe_{12}$. The developed PCM compositions can be used in the manufacture of tribotechnical parts for the agricultural, mining, and automotive industries, which operate in aggressive conditions (under the influence of UV radiation, variable temperatures, moisture, and abrasive particles). Applying them will not only reduce the mass of the structure, but also increase the service life of the equipment.

References

1. A.S. Kobets Application of polymer composites in the agricultural industry. Monograph. Dnipro: Zhurfond, 2022. 356 p. https://dspace.dsau.dp.ua/handle/123456789/7031

2. V.O. Melnyk Causes of wear of parts of friction units of aviation equipment and methods of ensuring their operability. Problems of friction and wear. Problems of Friction and Wear. 2020. Vol.86, No1. P. 87–92. https://doi.org/10.18372/0370-2197.86.14491

3. O. Shevchuk, U.Wagenknecht, S. Wiessner, N. Bukartyk, M. Chobit, V. Tokarev Flame-retardant polymer composites on the basis of modified magnesium hydroxide. Chemistry & Chemical Technology 2015. Vol. 9, No 2. P. 149–155. https://ena.lpnu.ua/handle/ntb/28323

4. T. Chang, C. Yuan, Z. Guo Tribological behavior of aged UHMWPE under water-lubricated condition. Tribology International. 2019. Vol. 133. P. 1–11. https://doi.org/10.1016/j.triboint.2018.12.038

5. Anuj Bellare, Alessandro Bistolfi, Saverio Affatato Ultra-High Molecular Weight Polyethylene: Influence of the Chemical, Physical and Mechanical Properties on the Wear Behavior. Materials. 2017, Vol.7, No10. P. 791. https://doi.org/10.3390/ma10070791

6. V.F. Bashev, A.-M.V. Tomina, K.A. Mykyta, T.V. Kalinina, S.I. Riabtsev, O.I. Kushnerov The influence of a rapidly-quenched filler on the wear resistance of ultrahigh molecular weight polyethylene. Functional Materials. 2024. Vol.31, №3. P. 387–390. http://functmaterials.org.ua/contents/31-3/387

7. M.M. Bratychak, N.V. Chopyk, V.M. Zemke Technological features of polymer blends processing based on ultra-high molecular weight polyethylene. Chemistry, Technology and Application of Substances. 2018. Vol.1, №1. P. 127–132. https://ena.lpnu.ua/handle/ntb/45022

8. O.I. Kushnerov, V.F. Bashev, S.I. Ryabtsev Structure and Properties of Nanostructured Metallic Glass of the Fe–B–Co–Nb–Ni–Si High-Entropy Alloy System. Nanomaterials and Nanocomposites, Nanostructure Surfaces, and Their Applications, Springer Proceedings in Physics. 2021. Vol.246. P.557–567. https://link.springer.com/chapter/10.1007/978-3-030-51905-6_38

9. O.I. Kushnerov, V.F. Bashev, S.I. Ryabtsev Structure and Properties of Melt-Quenched $Al_4CoCrCuFeNi$ High Entropy Alloy. Defect and Diffusion Forum. 2024. Vol.431. P.47–54. https://doi.org/10.4028/p-4GvJbC

10. Ye.A. Yeriomina, O.B. Lysenko, V.K. Nosenko, Ya.E. Yarovyi Study of the influence of quick-hardened alloy on the properties of metal polymers. Journal Of Physics And Electronics. 2021. Vol. 29, No.1. P. 41–44. https://doi.org/10.15421/332105

11. Ya.E. Yarovyi, Ye.A. Yeriomina, A.-M.V. Tomina The influence of nickel-clad chromium carbide on the tribological properties of composite based on phenylone aromatic polyamide. Functional Materials. 2025. Vol.32, No.1. P. 72–76. https://doi.org/10.15407/fm32.01.72

12. V.I. Dvoruk, Kindrachuk M.V. Physical nature of abrasive wear resistance of commercially pure metals. Problems of Tribology, 2011, No. 2. P. 79–85. https://tribology.khmnu.edu.ua/index.php/ProbTrib/article/view/335

Томіна А-М.В., Шурпік В.Ю., Єрьоміна К.А., Predrag Dašić, Бурзав В.Б. Вплив високоентропійних сплавів на показник абразивного стирання надвисокомолекулярного поліетилену

У роботі розглянуто вплив високоентропійних сплавів $Fe_{20}Ni_{20}Co_{20}Be_{20}Si_{14}B_6$ та $Al_{40}Co_{12}Cu_{12}Cr_{12}Ni_{12}Fe_{12}$ на показник абразивного стирання надвисокомолекулярного поліетилену. Зокрема, встановлено ефективний вміст наповнювачів, при яких досягається мінімальне значення показника абразивного стирання. Для сплаву $Fe_{20}Ni_{20}Co_{20}Be_{20}Si_{14}B_6$ такі значення спостерігаються при концентрації 25 мас.%, тоді як для сплаву $Al_{40}Co_{12}Cu_{12}Cr_{12}Ni_{12}Fe_{12}$ – при 20 мас.%. У досліджених інтервалах концентрацій спостерігається загальне покращення абразивної стійкості на 35–45% порівняно з вихідним ненаповненим поліетиленом, що свідчить про високу ефективність обраних порошкових наповнювачів. Підвищення зносостійкості пояснюється особливостями взаємодії твердих часток високоентропійних сплавів з полімерною матрицею. Завдяки мікротвердості, що перевищує 10000 МПа, такі частки виконують роль армуючих елементів, які рівномірно розподіляються в об'ємі поліетилену та сприяють формуванню більш стабільної та жорсткої структурної сітки. Це забезпечує ефективний опір механічному руйнуванню поверхневих шарів під час тертя по жорсткозакріплених абразивних частках, що особливо важливо для роботи вузлів тертя в умовах інтенсивних навантажень. Додатково встановлено, що твердість отриманих композитів зростає приблизно у 1,6 рази, що підтверджує підсилюючий вплив високоентропійних наповнювачів та позитивно відображається на експлуатаційній довговічності матеріалу. Отримані результати підтверджують доцільність використання порошків високоентропійних сплавів як перспективних функціональних наповнювачів для створення зносостійких полімерних композиційних матеріалів на основі надвисокомолекулярного поліетилену та окреслюють подальші напрями удосконалення технологій модифікації полімерів.

Ключові слова: надвисокомолекулярний поліетилен, показник абразивного стирання, високоентропійний сплав, полімерний композиційний матеріал