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INFLUENCE OF ALUMINIUM AND HIGH-ENTROPIC ALLOY $FeNiCoB_{0,7}Si_{0,3}BeNb$ ON THE ABRASIVE WEAR RATE OF ULTRA-HIGH-MOLECULAR-WEIGHT POLYETHYLENE

The article investigates the influence of industrial B95 aluminium alloy and the high-entropy alloy $FeNiCoB_{0,7}Si_{0,3}BeNb$ *on the abrasive wear rate of ultra-high-molecular-weight polyethylene. It is shown that the introduction of both metal fillers increases the wear resistance of ultra-high-molecular-weight polyethylene to the fixed abrasive particles by approximately 50%. This improvement is attributed to the strengthening of the surface layer of the polymer matrix resulting from the incorporation of solid filler particles. This effect is confirmed by an increase in the hardness of the material on the Rockwell scale (HRR) by approximately 35% and a reduction in surface roughness by 40%. It is found that the high-entropy alloy has a more pronounced effect on reducing the abrasive wear rate of the polymer matrix. In both cases, the optimal complex of an optimal combination of functional properties is observed for composite materials containing 25 wt.% of B95 and* $FeNiCoB_{0,7}Si_{0,3}BeNb$ *alloys. A further increase in the filler concentration in the polyethylene volume results in a reduction in abrasive wear resistance and hardness. This behaviour is explained by an increased number of structural defects in the polymer matrix, which degrade its mechanical integrity and reduce its ability to withstand external loads effectively.*

Key words: *ultra-high-molecular-weight polyethylene, aluminium alloy, high-entropy alloy, abrasive wear rate*

Introduction. A common reason for the deterioration in performance of tribological joints of modern technology containing steel parts is wear, which leads to a reduction in component service life and overall system reliability. One of the key factors contributing to such wear is insufficient heat dissipation from the contact zone, resulting from the low thermal conductivity of steel. This causes localised overheating of materials, increased friction, and intensive surface degradation. As a result, accelerated ageing of components occurs, accompanied by a reduction in their service life, which necessitates the development and improvement of materials and designs capable of efficient heat dissipation and wear reduction in tribological joints. An effective approach to solving this problem is using polymer composite materials (PCMs). Among polymers used for the development of new PCM compositions, ultra-high-molecular-weight polyethylene (UHMWPE) has attracted considerable attention, as its functional characteristics are comparable to those of high-performance materials such as polyetheretherketone (PEEK), polytetrafluoroethylene (PTFE) and polyoxymethylene (POM). UHMWPE is characterised by chemical inertness, excellent self-lubricating properties, corrosion resistance, high wear resistance (approximately 15 times greater than that of carbon steel), resistance to cavitation erosion and impact loading, including under cryogenic conditions, high toughness, as well as low static and dynamic coefficients of friction. Despite these advantages, UHMWPE has a number of disadvantages, including limited wear resistance under adhesive wear conditions, low thermal conductivity, and high melt viscosity, which complicates its processing using conventional methods. The introduction of dispersed metal fillers (FLs) into the composition – including aluminium-based binary alloys (Al–Co, Al–Cr, Al–Ni, Al–Mn), silver (Ag, including nanoparticles), copper (Cu and its oxides CuO), titanium and its alloys (Ti–6Al–4V), cobalt, and bronze (Cu–Sn powders) – enabled the development of such polymer composite materials that significantly exceed the original UHMWPE in terms of wear resistance and thermal conductivity [1-7]. In view of the above, this work aims to develop and study the tribological properties of new PCMs based on ultra-high-molecular-weight polyethylene filled with dispersed metal fillers.

Materials and research methods. UHMWPE produced by Jiujiang Zhongke Xinxing New Material Co., Ltd. (Jiujiang, China) [20] was used as a polymer matrix in the creation of composites containing dispersed metal FLs. UHMWPE belongs to the class of high-performance polymers and, in terms of its functional properties, is comparable to polytetrafluoroethylene, polyetheretherketone and polyoxymethylene [8]. The high molecular weight and supramolecular structure of UHMWPE determine its unique technical characteristics. Strong intermolecular interactions and intensive entanglement of polymer chains between UHMWPE macromolecules result in the formation of extensive physical bonding. This structure provides high impact strength and resistance to abrasive wear, as well as enhanced chemical and atmospheric resistance to aggressive environments, moisture, and X-ray and ultraviolet radiation. The operational properties of UHMWPE are directly related to its phase structure, which is formed by a combination of crystalline and amorphous regions. The supramolecular structure of polyethylene consists predominantly of an orthorhombic crystalline phase (approximately 60%), supplemented by a monoclinic crystalline phase (approximately 10%) and an amorphous phase (approximately 30%) [9]. The following materials were used as dispersed FLs:

- high-strength melt-liquid-quenched (MLQ) industrial B95 aluminium alloy, one of the strongest aluminium-based alloys. B95 belongs to the class of heat-strengthened alloys and contains magnesium, copper and zinc. This alloy is characterised by high hardness, ultimate tensile strength, heat resistance, resistance to corrosion cracking, and high compressive strength under dynamic loading [10]. Owing to the combination of low density and high mechanical performance, B95 is widely used in the aviation and aerospace industries;

- high-entropy alloy (HEA), a material composed of five or more metallic elements, each present in concentrations ranging from 15 to 35 at.%. In recent decades, HEAs have attracted considerable interest in materials science because they challenge conventional alloying principles by containing five alloying elements rather than a single dominant component. HEAs typically have a single-phase structure and are characterised by high resistance to wear, corrosion and oxidation, operational stability under dynamic loads, increased hardness, heat resistance, and plasticity. The first studies on HEAs were reported in 2004. With appropriate selection of components, it is possible to obtain substitution solutions even in systems containing a large number of components. HEAs may consist of one or two phases with bcc or fcc crystal lattices, or a combination of bcc and fcc phases [11]. Samples containing 15-30 wt.% FLs were manufactured by compression moulding; the detailed processing parameters are described in the works [5, 6]. The resistance of the developed polymer composite materials (PCMs) and pure polyethylene to the action of fixed abrasive particles (particle size 100 μm), as well as changes in the morphology of the friction surfaces, was evaluated using a HECKERT experimental machine and a probe profilometer (model 170621) [6].

Analysis of results and discussion. As shown by the data presented in Fig. 1, the introduction of 15–35 wt.% of B95 aluminium alloy and high-entropy alloy ($FeNiCoB_{0,7}Si_{0,3}BeNb$) reduces the abrasive wear rate of ultra-high-molecular-weight polyethylene by approximately 50%.

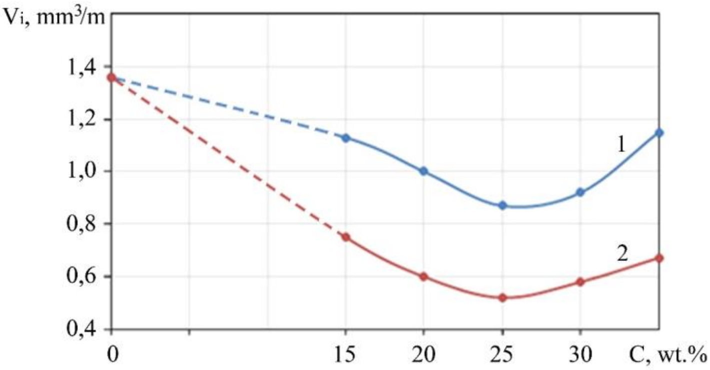


Fig.1. Influence of the content (C, wt.%) of B95 aluminium alloy (1) and $FeNiCoB_{0,7}Si_{0,3}BeNb$ (2) on the abrasive wear rate (V_i, mm^3/m) of ultra-high-molecular-weight polyethylene

The increase in the wear resistance of UHMWPE under the action of abrasive particles can be explained by the presence of dispersed FLs that reinforce the surface layer of the material because of their high hardness. This results in enhanced resistance to destructive processes associated with the cutting action of abrasive particles. This conclusion is confirmed by a 40% reduction in the roughness of the friction surfaces (see Fig. 2). In addition, the introduction of aluminium and high-entropy alloys contributes to a reduction in the intensity of microcrack formation and plastic deformation in the friction zone. This, in turn, ensures a more uniform distribution of the applied load (10 N) over the friction surface of the PCM and reduces stress concentration in critical regions, which is particularly important for preventing premature loss of wear resistance [12]. Further evidence of the increased resistance to deformation is provided by a comparison of the friction surfaces of UHMWPE (Fig. 3a) and the PCM based on it (Fig. 3b, c), obtained by optical microscopy.

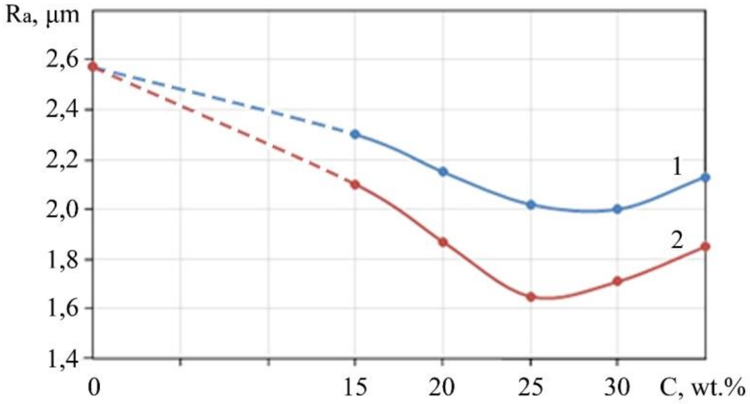
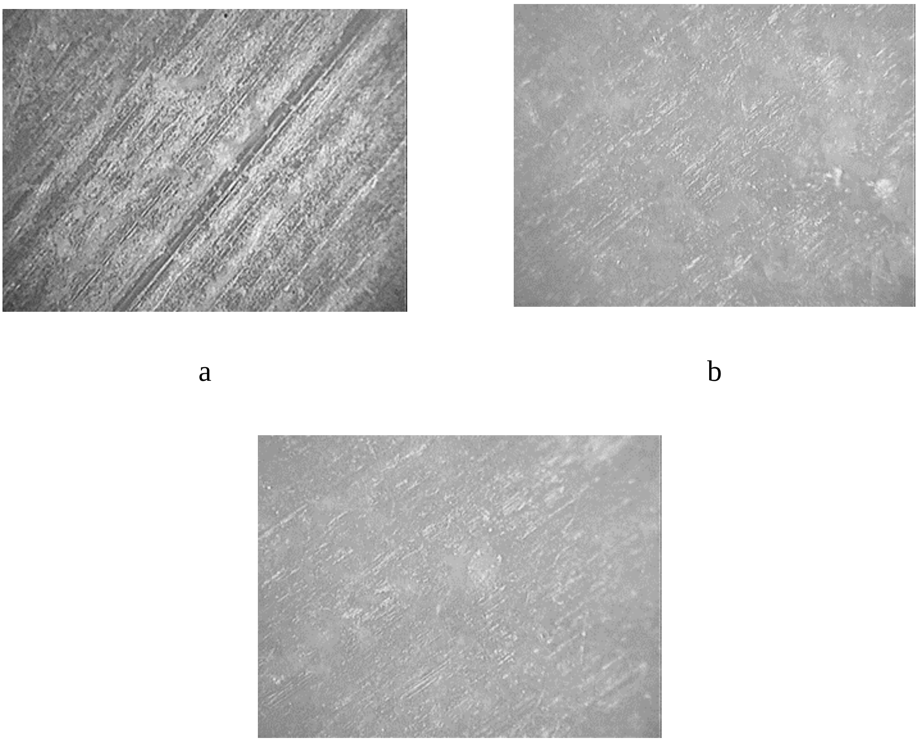


Fig.2. Influence of the content (C, wt.%) of B95 aluminium alloy (1) and $FeNiCoB_{0,7}Si_{0,3}BeNb$ (2) on the roughness (R_a, μm)



a b

c

Fig.3. Friction surfaces (×200) of UHMWPE (a) and PCM based on it, containing 25 wt.% B95 aluminium alloy (b) and $FeNiCoB_{0,7}Si_{0,3}BeNb$ (c)

It was found that the introduction of B95 or HEA into UHMWPE leads to a reduction in the depth of ploughing furrows. The strengthening of UHMWPE occurs because hard particles of solid FLs complicate dislocation motion in the material under the applied load. This effect is confirmed by an increase in the Rockwell hardness (HRR) of UHMWPE by approximately 35%.

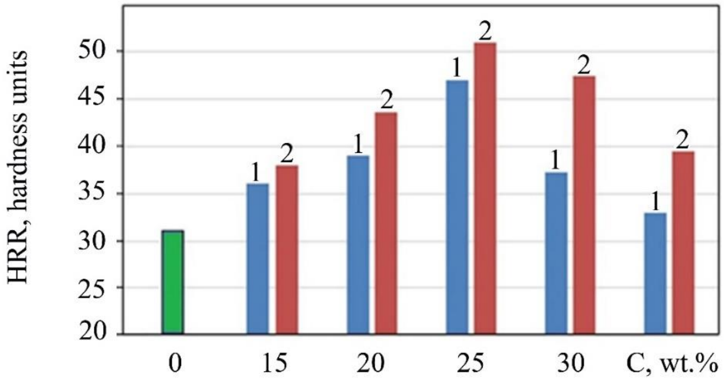


Fig.4. Influence of the content (C, wt.%) of B95 aluminium alloy (1) and $FeNiCoB_{0,7}Si_{0,3}BeNb$ (2) on the hardness (HRR, hardness units) of ultra-high-molecular-weight polyethylene

It should be noted that the reduction in the abrasive wear rate of UHMWPE is more strongly influenced by the high-entropy alloy (HEA). This can be explained by the fact that the presence of seven components in an equiatomic ratio provides the alloy with high entropy, while the significant differences in the atomic radii of the HEA components (Fig. 5) lead to the formation of a crystal lattice subjected to a high level of lattice distortion ($\geq 2{,}7\cdot 10^{-3}$). This, in turn, imparts high hardness (HV~10,000 MPa) and enhanced wear resistance to the HEA. In addition, the ratio of components in certain proportions leads to the formation of alloys with a mixture of bcc and fcc lattices [11].

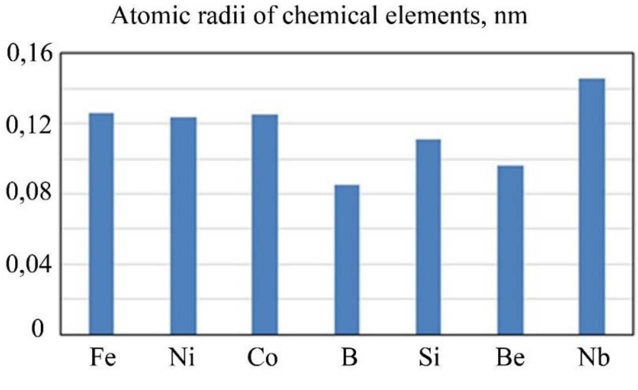


Fig. 5. Comparison of the atomic radii (nm) of the chemical elements comprising the HEA

According to the literature [11], the number of slip planes in bcc and fcc lattices differs, with the fcc structure possessing the greatest number of slip planes. Therefore, HEAs with a bcc lattice exhibit high hardness but relatively low plasticity, whereas alloys with an fcc lattice demonstrate greater plasticity but lower hardness. It should be noted that PCMs containing 25 wt.% of B95 or HEA exhibit an optimal combination of functional properties. A further increase in the FLs concentration within the UHMWPE leads to a deterioration in abrasive wear resistance and hardness. This behaviour is likely associated with an increase in the number of structural defects in the polymer, which reduces its mechanical integrity and load-bearing capacity. The formation of such defects can be explained by the interaction between dispersed particles of B95 and HEA arising from strong bond energy and Van der Waals forces. These interactions contribute to the agglomeration of FLs particles, which in turn leads to the formation of larger clusters containing internal voids and exhibiting a reduced contact area with the UHMWPE [12].

Conclusions. Analysis of the obtained results demonstrated that using dispersed fillers with a particle size of 50–100 μm (aluminium alloy or high-entropy alloy $FeNiCoB_{0,7}Si_{0,3}BeNb$) in UHMWPE is an effective approach for improving its functional properties, resulting in reductions in the abrasive wear rate and surface roughness by approximately 50% and 40%, respectively. It was found that the optimal filler content for UHMWPE is 25 wt.% of B95 or HEA. The developed PCM can be used for the manufacture of wear-resistant components for agricultural and automotive equipment operated under aggressive conditions, particularly in environments involving exposure to acids, alkalis and abrasive particles.

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ВПЛИВ АЛЮМІНІЄВОГО ТА ВИСОКОЕНТРОПІЙНОГО СПЛАВУ $FeNiCoB_{0,7}Si_{0,3}BeNb$ НА ПОКАЗНИК АБРАЗИВНОГО СТИРАННЯ НАДВИСОКОМОЛЕКУЛЯРНОГО ПОЛІЕТИЛЕНУ

У статті досліджено вплив промислового алюмінієвого сплаву В95 та високоентропійного сплаву $FeNiCoB_{0,7}Si_{0,3}BeNb$ на показник абразивного стирання надвисокомолекулярного поліетилену. Встановлено, що введення обох металевих наповнювачів забезпечує підвищення зносостійкості надвисокомолекулярного поліетиленову до дії жорскозакріплених часток абразиву приблизно на 50%. Покращення зазначеного показника обумовлено зміцненням поверхневого шару полімерної матриці внаслідок введення твердих часток наповнювача. Це підтверджується збільшенням твердості матеріалу за шкалою Роквелла (HRR) приблизно на 35% та зменшенням шорсткості поверхні на 40%. Встановлено, що більший виражений вплив на зниження показника абразивного стирання полімерної матриці чинить високоентропійний сплав. В обох випадках оптимальним комплексом функціональних властивостей характеризуються композиційні матеріали із вмістом 25 мас.% сплавів В95 та $FeNiCoB_{0,7}Si_{0,3}BeNb$. Подальше збільшення концентрації наповнювача в об'ємі поліетилену призводить до зниження абразивної зносостійкості та твердості матеріалу. Це пояснюється зростанням кількості структурних дефектів у полімерній матриці, які погіршують її механічну цілісність і здатність ефективно протистояти зовнішнім навантаженням.

Ключові слова: надвисокомолекулярний поліетилен, алюмінієвий сплав, високоентропійний сплав, показник абразивного стирання

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