ISSN 1027-5495. Functional Materials, 31, No.2 (2024), p. 557-560
doi:http://dx.doi.org/10.15407/fm31.02.557

Effect of binary Al-Ni alloy on the rate of abrasive wear of ultra-high molecular weight polyethylene

V.F. Bashev[1], S.V. Tomin[1], T.V. Kalinina[1], O.I. Kushnerov[2], N.P. Bondar[1]

[1]Dniprovsk State Technical University, Kamyanske
[2]Oles Honchar Dnipro National University, Dnipro

Received June 10, 2024

The paper investigates the influence of the content of Al-Ni alloy quenched from the molten state on the abrasive wear rate of ultra-high-molecular-weight polyethylene on rigidly attached abrasive particles. Studies have shown that the addition of 5–30 mass% of the quenched aluminum alloy to ultra-high-molecular-weight polyethylene reduces the rate of abrasive wear by ~ 50%. The improvement of this indicator is due to the high values of microhardness, dislocations density, and microstresses of rapidly quenched Al-Ni alloys.
Keywords: ultra-high-molecular-weight polyethylene, lattice period, microhardness, microstress, binary alloy, abrasive wear rate, abrasive particles.

Вплив бінарного сплаву системи Al-Ni на показник абразивного стирання надвисокомолекулярного поліетилену. *В.Ф. Башев, С.В. Томін, Т.В. Калініна, О.І. Кушнерьов, Н.П. Бондарь*

У роботі досліджено вплив вмісту загартованих з рідини сплавів системи Al-Ni на показник абразивного стирання надвисокомолекулярного поліетилену по жорстко закріпленим абразивним часткам. Дослідження показали, що введення до надвисокомолекулярного поліетилену 5–30 мас.% загартованого алюмінієвого сплаву зменшує показник абразивного стирання на ~ 50%. Покращення цього показника обумовлено високими значеннями мікротвердості, густини дислокацій і мікронапружень у швидкозагартованих сплавах Al-Ni.

1. Introduction

Friction units of modern machinery, which are equipped with serial metal parts, often work under the influence of increased loads, sliding speeds, temperatures, abrasive particles (rock, alumina, sand) and moisture; these factors lead to premature wear and, as a result, a decrease in their efficiency. This may lead to emergency situations and increased time for maintenance, repair and replacement of friction unit parts. The solution to this problem is the use of modern polymer composite materials (PCMs). It is known that the use of parts from PCMs leads to a reduction in costs aimed at the purchase of spare parts and materials for their manufacture, and, as a result, to a decrease in the number of technical personnel involved in maintenance and repair of equipment. Among the numerous fillers (FLs) for PCMs of tribotechnical purpose, it is worth highlighting powders of metals and alloys. It is known that the use of aluminum bronze, molybdenum diselenide, powders of alloys based on copper, carbonyl nickel, aluminum, PR-N65H25S3R3 self-fluxing alloy, an alloys of the Ti-Al-V system, zirconium oxide, magnesium, and zinc as FLs allows us to create metallopolymers (MPs) with high self-lubricating ability under conditions of high-speed sliding, as well as with high indexes of hardness, thermal conductivity, strength, thermal resistance, wear resistance under the influence of abrasive particles and increased loads [1-8]. Considering the above, this work is aimed at the development and research of new MPs with high tribological properties.

2. Experimental

When creating new MPs, the widely used ultra-high-molecular-weight polyethylene (UHMWPE) (produced by Jiujiang Zhongke Xinxing New Material Co., Ltd., China) was chosen as the polymer matrix. UHMWPE is characterized by a high ability to evenly dissipate mechanical energy, resistance to cracking, shock and fatigue loads. The stability of work under the influence of water, moisture, microorganisms, and UV radiation should also be included among the advantages of UHMWPE. This is due to the fact that UHMWPE does not contain chemical groups (esters, amides or hydroxyl groups) in the main chain, which are unstable to the influence of aggressive substances. Technical characteristics of ultra-high-molecular-weight polyethylene of this brand are given in [9].

The Al-Ni system binary alloy quenched from the molten state (cooling rate is ~10^6 K/s) is characterized by the combination of unique physical and mechanical properties due to the presence of a single-phase highly supersaturated solid substitution solution in the quenched structure; therefore, it was chosen as a powder (dispersion is 50-100 μm) metallic FL for UHMWPE. The state diagram of Al-Ni is characterized by the almost absence of solubility of Ni atoms in the FCC lattice of Al. Quenching from the molten state (QMS) allows you to significantly increase the solubility of Ni in aluminum up to 10%, as evidenced by the crystal lattice period of the quenched Al-Ni alloy (Fig. 1). X-ray structural analysis of the Al-Ni alloys quenched from the molten state (3, 5, 10 mass% Ni) showed the presence of only fcc lines of a single-phase solid solution, which is explained by the complete replacement of Al atoms by all Ni atoms.

The high level of mechanical properties of the alloy is caused by a significant difference in the interatomic radii of Al (r = 0.141 nm) and Ni (r = 0.128 nm), which leads to the occurrence of significant microstresses in the FCC-Al lattice under conditions of non-equilibrium crystallization. Fig. 1 shows that the degree of elastic strains of the lattice increases with increasing Ni content; this is confirmed by the high level of

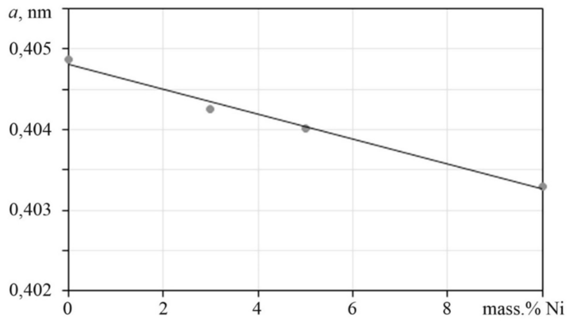

Fig.1 Dependence of the crystal lattice period of QMS-samples on the Ni content in the Al-Ni alloy

microstresses (Fig. 2) up to almost $\Delta a/a$~$3\cdot10^{-3}$, which is responsible for the low values of the abrasion index. At the same time, QMS leads to the crushing of the so-called regions of coherent scattering of X-rays, which is accompanied by a significant increase in the density of dislocations up $2\cdot10^{11}$ cm^{-2}. It also contributes to the growth of mechanical properties [10]. The determined parameters of the fine structure (density of dislocations and microstress) have a positive effect on the level of mechanical properties of the materials. According to the method given in [10], the parameter $\Delta a/a$ of the Al-Ni binary alloy quenched from the molten state was calculated:

$$\frac{\Delta a}{a} = \frac{\beta}{4\cdot tg\theta}$$

where β is the integral width of the diffraction line (222); θ is the reflection angle.

Grinding of the Al-Ni binary alloy (3, 5, 10 mass% Ni) was carried out in a special laboratory grinder. Next, the crushed alloy was sieved using laboratory sieves to obtain the required dispersion of the samples. The formation of MPs based on UHMWPE containing 5–30 mass% of dispersed (50-100 μm) alloy Al-(3, 5, 10 mass%) Ni was carried out by the method of compression pressing, the method described in [9].

The resistance of the developed MPs and the initial polymer to the impact of harshly fixed abrasive particles (dispersity is 100 μm) was evaluated using the HECKERT test machine. Each sample passed a preliminary test in the working mode until full contact with the abrasive skin before starting the research. During the experiment, the load on the sample was 10 N, and the length of the friction path was 40 meters. The value of the abrasive wear rate (V_i, mm^3/m) was calculated according to the formula:

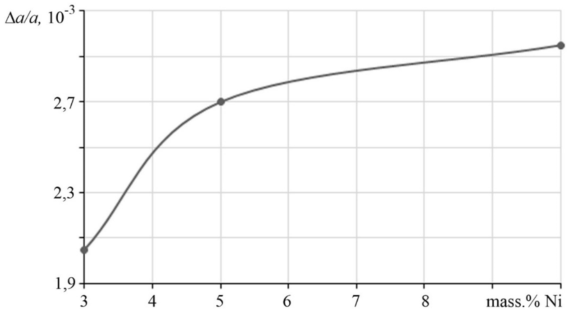

Fig. 2 – Dependence of the magnitude of microstresses ($\Delta a/a$) on the Ni content

$$V_i = \frac{\Delta G \cdot 1000}{\rho \cdot L}.$$

where ΔG is the value (g) of weight wear of samples, determined using VLR-200 analytical scales with an accuracy of up to 0.00001 g; ρ_e is the experimental density (g/cm^3) of the wearable material, determined by hydrostatic weighing [9]; 40 m is the distance traveled by the test sample during one test cycle.

The morphology of the friction surfaces of UHMWPE and MPs based on it was compared using a BIOLAM-M microscope. The microhardness (HV, MPa) of the Al-Ni binary alloy was determined using a PMT-3M tester under the load of 20 g. The roughness (R_a, μm) of the friction surfaces was measured using a probe profilometer model 170621.

3. Results and discussion

It can be seen from the data shown in Fig. 3 that the introduction of the Al-Ni binary alloy quenched from the molten state in the amount of 5-20 mass% to UHMWPE leads to a decrease in its abrasive wear rate by almost 50%. This confirms the fact that the developed new MPs are characterized by high deformation-strengthened properties [11] compared to the original UHMWPE. It should be noted that lower values of abrasive wear rate are observed for MCs doped with a binary alloy at an optimal Ni content of 10 mass%, for which the highest level of microstresses (kind II stresses) was obtained. Comparison of the morphology of the friction surfaces of MP and UHMWPE confirms this. The microrelief of the friction surfaces shows a more uniform structure of the developed MP (Fig. 4, b-g) with fewer signs of wear (the depth of plowing furrows is 25% less) compared to pure ultra-high-molecular-weight polyethylene (Fig. 4, a).

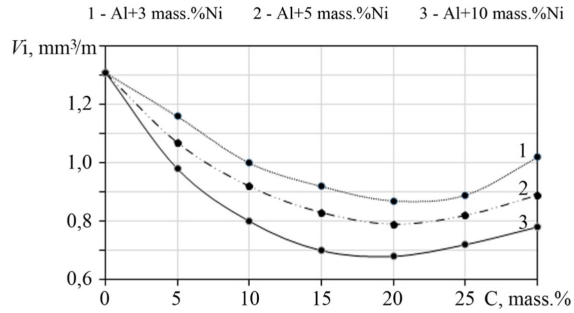

Fig. 3 – Influence of the percentage content of the filler on the rate of abrasive wear (average value of five test cycles) of ultra-high-molecular-weight polyethylene

The increase in resistance to abrasion of MPs is due to the high hardness of FLs. Studies showed that the microhardness of the Al-Ni binary alloy is 350-580 MPa. FL particles strengthen UHMWPE, thereby ensuring effective load distribution and preventing its excessive wear, which ultimately increases the service life of the material.

With an increase in the amount of FL to 25-30 mass%, an increase in the intensity of abrasive wear is observed. The reason is that due to the high intermolecular energy of the components (E(Al)=3.1·10^5 J/mol and E(Ni)=4.22·10^5 J/mol) [12], it is difficult for the particles of the binary Al-Ni alloy [12] to be evenly distributed in the volume of UHMWPE; they "stick together", resulting in the formation of agglomerates with a smaller contact surface with UHMWPE.

4. Conclusion

The analysis of the obtained results on the functional properties of the developed MPs indicates the potential of using Al-Ni alloys as FLs for UHMWPE. The QMS method used in the work ensures the formation of single-phase strongly supersaturated solid substitution solutions with a very high elastic deformation of the lattice, which determines the high wear resistance of the developed MPs to the impact of abrasive particles. The optimal concentration of FL is 20 mass%. The developed MPs can be effectively used for the production of parts of agricultural machinery and the mining industry operating under conditions of exposure to abrasive particles and aggressive environments (hydrochloric acid, diesel fuel, acetone): liners, cogwheels, gears, support rollers, cable blocks, pressure bars, valves, pulleys, etc.

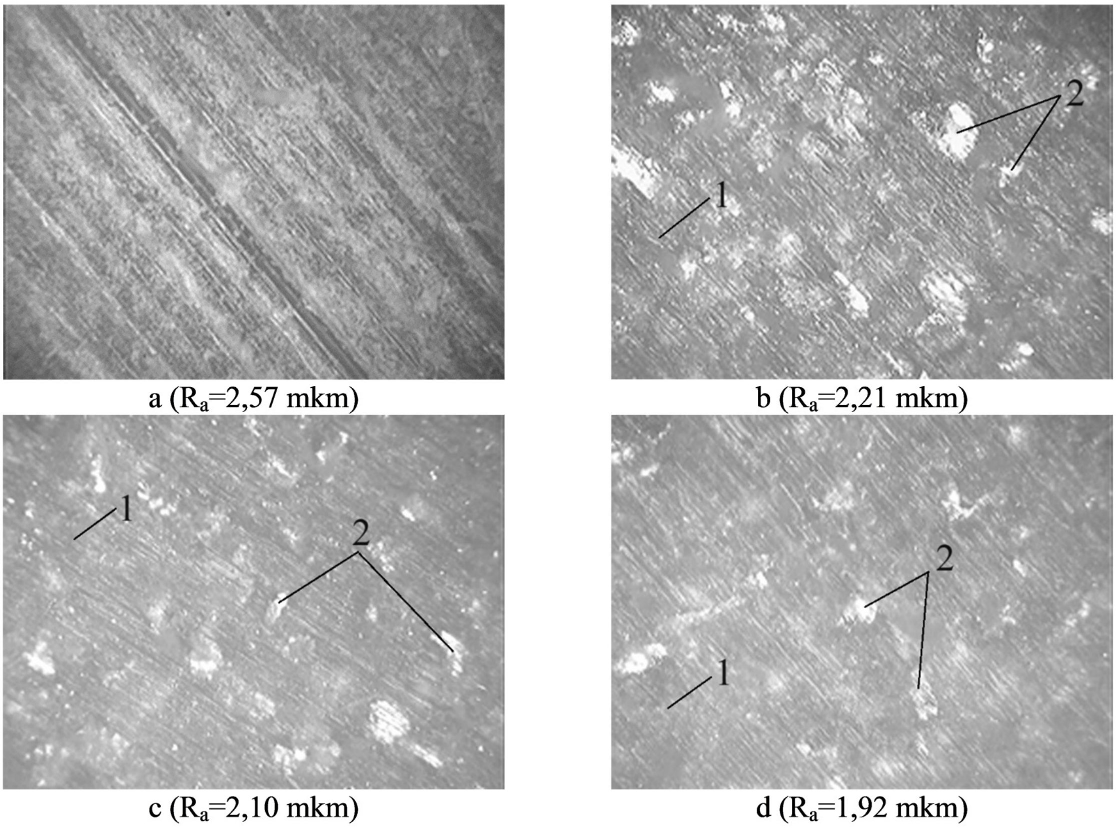

Fig. 4 – Friction surfaces (×200) of UHMWPE (a) and metal containing polymers based on it containing 20 mass% of a binary alloy of the Al-Ni system with 3(b), 5(c), and 10(d) mass% Ni in Al: where 1 –- polymer matrix; 2 – binary alloy

References

1. Patent 17852A Ukraine, MPK (2006.01) F16C 33/04.
2. Patent 101050 Ukraine, MPK (2006.01) C08L 75/04.
3. Patent 92212 Ukraine MPK (2014.01) C08L 77/00
4. O. Burya, Ye. Yeriomina, O. Lysenko, A. Konchits, A. Morozov, Polymer composites based on thermoplastic binders, Srednyak T. K. Press (2019).
5. K.A. Yeriomina, O.B. Lysenko, V.K. Nosenko, Ya. E. Yarovyi. *J. Physics and Electronics*, 29, 1 (2021).
6. K.S. Kanaga Karuppiah, A.L. Bruck, S. Sundararajan, J. Wang, Z. Lin, Z.-H. Xu, X. Li. *Acta Biomater*, 4 (2008).
7. Muzamil Hussain, Rizwan Ali Naqvi, Naseem Abbas, Shahzad Masood Khan, Saad Nawaz, Arif Hussain, Nida Zahra, Muhammad Waqas Khalid. *Polymers (Basel)*, 12, 2 (2020).
8. A.I. Burya, Ye.A. Yeriomina, *J. Friction and Wear*, 37, 2 (2016).
9. A.-M.V. Tomina, O.V. Yeromenko, *Functional Materials*, 30, 3 (2023).
10. S.I. Mudryi, Y.O. Kulik, A.S. Yakymovych, X-ray structural analysis in materials science. teaching method manual. LNU named after I. Frank., Lviv (2017).
11. A. Dobrovolsky, V. Kosenko, *Mining, constructional road and melioration machines*, 87 (2016).
12. M.V. Kindrachuk, V.I. Dvoruk. *J. Problems of Tribology*, 2 (2011).