UDK 621.891 (043.3) DOI: 10.18372/0370-2197.1(102).18387

O. TAMARGAZIN, L. PRYIMAK, I. MORSHCH

National Aviation University, Ukraine

SUBSTANTIATION OF EXPEDIENCY OF USE OF TOOL HIGH-SPEED CUTTING STEELS AS COATINGS IN FRICTION UNITS

The analysis of modern researches in the field of composite materials on the basis of tungsten carbide used as surfacing materials is carried out. In particular, the influence of morphology of carbide phase on wear resistance of materials is analyzed. Particular attention is paid to the analysis of conducted studies of ultrafine and nanograined composite materials, their comparative analysis with conventional micrograin coatings. The expediency of research of application of tool high-speed steels as coatings, applied by vacuum electron-beam processing method, which allows to organize micro-metallurgical process with minimal impact on the base metal and possibility to form hardened layer, the thickness of which is adjustable within wide limits, is substantiated.

Keywords*: composite materials, structural-phase composition, serviceability, cladding.*

Introduction. Nowadays composite materials are widely used in aircraft construction [1]. High hardness of these materials makes them attractive as wear-resistant materials, but, unfortunately, they have high brittleness, which limits their suitability in conditions of intensive wear. In particular, metal-ceramic materials consist of a solid phase, such as tungsten carbide (WC), combined with a more ductile metallic phase, often cobalt or nickel. A typical process for manufacturing oversized parts based on ceramic-metal materials for wear applications involves powder compaction followed by hot isostatic pressing. This processing is often expensive and is limited to the manufacture of relatively small parts. At the same time, the wear resistance of the parts is determined only by the properties of the contacting surface. Consequently, the use of coating methods (cladding or spraying) has some advantages in creating wear-resistant coatings. In particular, coating gives an opportunity to produce parts of any size with metal-ceramic coating only in the area of their working surfaces. This allows the use of cheaper and lighter metal substrates as the main bearing element and makes it possible to repair damaged or worn areas [2].

Literature data analysis and the state of the problem. Very often tungsten carbide-based alloys are used as composite materials used as surfacing materials. Tungsten carbide has high hardness and strength, shows high performance properties and has some ductility [3]. Tungsten carbide has good tribological properties due to its excellent adhesion to the substrate, good bonding, low porosity, low tendency to form brittle phases during sputtering and high hardness. This makes tungsten carbide a good choice for aerospace applications.

The sliding friction wear of WC-Co carbide alloys has been studied in various environments [4,5]. In particular, friction and wear tests have been conducted using three different types of carbides based on tungsten, titanium and chromium carbides paired with a steel disk under dry sliding conditions. The published data show that the wear resistance of these materials in friction conditions without lubrication is high and depends on the carbide/bond ratio, carbide grain size, and also strongly depends on the bulk hardness of the material. The wear rate increases with decreasing bulk hardness.

TiC- and Ti(CN)-based carbide alloys also have a sufficiently high wear resistance [2]. They are usually used for special equipment operating in corrosive-erosive and high-temperature environments. Due to their low density, TiC-based alloys have an attractive combination of high values of special mechanical properties such as strength/density. In particular, TiC-based alloys are used as O-ring seals in mechanical and floating O-ring seals, especially in corrosive and erosive environments.

$C_{r3}C_2$-based alloys are a relatively new development. Their tribological properties are still insufficiently studied in comparison with alloys based on WC-Co. The sliding friction wear of chromium carbide-based carbide alloys has been studied in [7,8]. However, the sliding friction wear of $C_{r3}C_2$-NiCr system coatings is more studied. Due to high hardness, good quality of surface polishing and thermal conductivity like steels, as well as due to high corrosion resistance in aggressive media and at high temperatures, these materials can be successfully used for the manufacture of sliding bearings and seals, especially designed to work in corrosive environments, which is very important for many products of aviation equipment. As a rule, alloys of $C_{r3}C_2$-Ni system have less erosion resistance than alloys of WC-Co system. But Cr3C2-Ni alloys have higher erosion resistance than other types of technical ceramics.

When adding 25-30% Cr to cobalt, a composition is obtained that has a region of structural $\alpha \rightarrow \gamma$ transformations at 1100-1200 K, the extremely low rate of which opens up the possibility of obtaining alloys that are highly stable at elevated temperatures. Stellite as an alloy based on utilization of this feature of Co-Cr system contains 0.5-3.0% C, 40-60% Co, 25-33% Cr and 3-17% W. In addition, this alloy may include nickel and molybdenum. In addition, stellite has a high level of heat, wear and corrosion resistance. Good machinability of stellite by cutting and high level of hardness at temperatures 650-1000 K suggest the possibility of its use for hardening of aircraft parts operating under conditions of high-temperature heating.

For parts of aviation equipment operating under medium wear conditions, such hard alloys are also used, the structure of which consists of special carbides (WC, TiC, TaC) associated with cobalt, as well as high-carbon steels such as P18, 10P6M5, X12, X12M with the structure of martensite-carbides.

Problem statement. In this publication the following questions concerning the problem to be solved are considered:

- tribological subsystems of various types of friction units of brake units;
- time dependences of the main operational parameters of friction pairs of the belt-pad brake at tests;
- discussion of results.

The aim of the work is to substantiate the interdependence of wear-friction properties and energy loading of belt-pad-brake friction pairs.

Steels of different structural classes. Nowadays many parts in mechanical engineering working in conditions of shock-no-abrasive wear are made of steel 110Г13Л. This steel has a unique combination of properties, due to which it is still difficult to find a substitute (relative elongation, impact toughness, cold-break threshold).

According to [9] the hardening mechanism of austenite of 110Г13Л steel is the change of fine crystal structure. Plastic deformation causes local texturing, fragmentation of grains, dislocation propagation and pulverization of the block structure. At strain rates of 50-80%, mechanical twinning takes place when the limiting dislocation density is reached [10]. This contributes to additional hardening, since the twin boundaries are effective barriers to dislocation motion.

The paper [11] describes the possibility of the appearance of martensitic α and ε phases in the microstructure of clad 110Г13Л steel. The paper explains it by microsegregation of carbon with the formation of carbides and decarburization of neighboring sites, which leads to the loss of solid solution stability and activation of γ→α and γ→ε transformations. Carbide precipitation is also possible at local heating under shock loading and friction. The paper [12] describes γ→α martensitic transformation at plastic deformation of surface layers of 110Г13Л steel, depleted of carbon and manganese as a result of burnout during casting. However, in all cases due to the small amount of martensitic phase (less than 2%) it does not have a significant effect on the hardening kinetics.

Currently, many works are aimed at replacing 110Г13Л steel with metastable austenitic steels (MAS), in which the Bogachev-Minz principle is realized, which consists in the phase overlap of metastable austenite during plastic deformation due to the formation of deformation martensite.

MAS operating under abrasive wear conditions combined with impact or micro-impact loads requires a combination of optimal kinetics of γ→α transformation and strain hardening of the solid solution [13]. At small degrees of deformation unstable chromium-manganese steels of 30Х10Г10 type with carbon content of 0.3-0.6% with a tendency to martensitic transformation are preferable. Small share of hardening of low-carbon austenite is compensated by martensitic phase. The martensitic framework, which is formed along the boundaries of austenite grains, prevents the material from unstrengthening under contact-impact loading.

Nowadays, more and more attention is paid to high-speed steels as materials that can be used as wear-resistant coatings. In [14], the effect of laser remelting on the microstructure and properties of M2 tool steel was investigated. Similar results were obtained for other types of high-speed steels such as T15. In [15], an electron beam combined with a laser was used to melt the surface of high-speed steels (HSS) rollers and to study the effect of the process on the microstructure of the steel. In [16], laser cladding technology was used to produce a coating of high-speed steel on carbon steel substrates. At the same time, the influence of the laser cladding process of M2 steel-based coatings on medium carbon steel and its microstructure was studied.

To investigate the effect of wear conditions of M2 steel on its mechanisms, tests were carried out in which a HSS disk was abraded in a pair with a disk made of M2 steel. The tests were conducted in dry conditions and with water lubrication. The pressing force was 2.5 kg, which gave a pressure of 690 MPa. The test disk was heated to temperatures of 700-900 K for the tests.

In the course of these studies it was revealed that the coefficient of friction increases linearly with increasing temperature both in dry and wet conditions, and in wet conditions it increases much more strongly. This can be explained by differences in the actual contact areas. Two main wear mechanisms were identified during the tests - oxidative wear and metal plowing. Both of these mechanisms are closely related to the test temperature. The degree of surface oxidation increases with increasing temperature. In addition, the oxides mechanically mix with the surface metal, resulting in a high degree of plastic deformation. The proportion of metal in wear products also increases significantly with increasing temperature, indicating that plowing wear begins to prevail over oxidative wear. As a result of research it was found that the resistance to erosion of coatings based on high-speed steels is three times higher compared to TiN coatings and seven times higher compared to Ti(C,N) coatings.

In [17], the wear mechanisms of WC-Co and HSS coatings obtained using hot isostatic pressing technology were studied. The tests were carried out on wear with an unfastened abrasive, which was quartz sand. For all samples the wear rate varied proportionally to the applied load and distance traveled. Samples with cobalt content of 20-24% wore much faster than samples with cobalt content of 6-9%. The established wear rate of high-speed steels approached the wear rate of samples with high cobalt content, which may indicate the same wear mechanisms in these samples. In samples made of high-speed steel and with a high content of cobalt bond, wear occurs by the mechanism of plowing and preferential removal of the matrix with subsequent precipitation of carbide grains. In the case of samples containing a small amount of binder, wear occurs by the mechanism of gradual cracking of carbide grains.

The study of friction and wear of high-speed steels and high-chromium cast irons in pair with carbon steel was carried out using the "disk-disk" system at temperature 1000 K and pressure 300 N. The microstructure of high-speed steel samples was represented by tempering martensite surrounded by an interdendritic network of eutectic carbides. The microstructure of the high-speed steel samples was temper martensite surrounded by an interdendritic network of eutectic carbides. In the wear test, in the case of high-speed steels, the outer regions of the specimens were most strongly oxidized, while in the case of high-chromium cast irons, the central parts of the specimens were most strongly oxidized. The test results showed that the volumetric mass loss of high chromium cast iron samples significantly exceeded the analogous values of high-speed steel samples, and the difference between the values increases with increasing sliding length. It was revealed that the wear resistance of high-speed steels directly depends on their hardness and the amount of carbide phase, while the wear resistance of cast irons depends more on the value of intercarbide distance and the formation of surface oxide films. These films protect the base metal from abrasion by changing the type of contact from "oxide-metal" to "oxide-oxide". The wear mode changes from adhesive at the initial stage to oxidative. In the case of high-speed steels such a transition is not observed.

Microstructure of coatings. At the same time, the question of the size of hardening particles of wear-resistant coatings remains open. Nowadays considerable attention is paid to the research of ultrafine-grained and nanograined composite materials showing better performance and higher wear resistance in comparison with conventional micro-grained coatings. Achievement of improved wear resistance in thermally filed coatings of WC-Co system is possible due to the presence of nanostructured carbides. Thermally milled coatings made of nanostructured WC-Co powder showed improved wear resistance compared to the conventional WC-Co powders milled in the same way. But at the same time, in spite of hardness more than 40 GPa of nanostructured coatings, their applicability is strongly limited by increased brittleness, especially under impact. The use of nano-sized carbide powders as raw materials leads to excessive decomposition during thermal application and to brittle coatings with low wear resistance.

Thermally filed WC-Co coatings form complex multiphase microstructures with a significantly lower volume fraction of primary carbide than the original powders. De-composition increases at high temperatures and low speeds if the particles have an open, porous structure that heats up quickly and the particles have small carbide grain sizes. All this increases carbide dissolution in the melted matrix and subsequent decarbonization, which in turn reduces abrasive wear resistance [2].

It was shown in [18] that, under conditions of medium to mild abrasive wear, ultrafine grains exhibit higher wear rates than conventional micron grains. This effect was considered on the basis of effective wear mechanisms, i.e., the rate of material removal by ploughing observed for ultrafine grains may be higher than the preferred bond removal following WC grain separation studied for micron grains. This situation can occur if the abrasive particles are comparable in size to WC grains in micron grain WC-Co composites, but larger in ultrafine grain WC-Co composites.

Therefore, it may be reasonable to combine nanoscale and microscale hardening particles. The friction wear resistance of nanostructured, bimodal and conventional WC-Co coatings deposited by high-speed oxygen sputtering was investigated using ball-disc tests with a WC-Co counterbody, a relative rotation speed of 140 rpm and a total test length of 1500 m, and dry abrasion tests with a rubber wheel at a rotation speed of 140 rpm, a load of 50 N and a SiO_2 flow of 300±5 g/min.

The grains of WC nanostructured powder had sizes less than 100 nm. The bimodal powder was a mixture of micron-sized particles of 1.5-3.5 μm and nanosized particles of 20-60 nm. The ratio of microstructural particles to nanostructural particles in the bimodal powder is 70/30. Finally, the conventional powder had WC particles of 2-5 μm in size.

Two wear mechanisms were found in the studied samples. In some areas, preferential destruction of the cobalt matrix followed by deterioration of the bonding of WC grains due to matrix loss and precipitation of WC grains was observed. The bonding between WC grains and matrix in both nanostructured and bimodal coatings appears to be better than in the case of conventional coating. A decrease in carbide grain precipitation was observed and high wear resistance was achieved.

Thus, when comparing the conventional coating with the nano-structured coating, the lower coefficient of friction and the profilometry results for the nano-structured coating suggest that it has better sliding wear resistance than the conventional coating. In this case, despite the presence of a higher amount of W_2C phase, the higher microhardness of the nanostructured coating is the decisive factor affecting the wear resistance. When comparing the nanostructured and bimodal coatings, the lower coefficient of friction of the bimodal coating shows that this coating has a higher sliding friction wear resistance. Both coatings exhibit the same content of brittle phase W_2C. Thus, despite the lower microhardness than the nanostructured coating, the lower dissolution of WC nanostructured particles and the deposition of these nanostructured carbides in the spaces between micron carbides in the bimodal coating prevents matrix wear during the test.

Both nanostructured and conventional coatings showed similar abrasive wear resistance, despite the higher decarbonization experienced by the nanostructured coating. The high homogeneity of the dispersion of WC grains in the nanostructured coating is favorable for improving its wear resistance notwithstanding that the strong decarbonization observed in this coating is very detrimental. The presence of brittle W_2C phase and brittle bonding favors crack propagation and severe deterioration of the wear resistance of the nanostructured coating. The bimodal coating showed half the abrasive wear rate - meaning that it has twice the abrasive wear resistance compared to other coatings. In this case, decarburization leads to hardening of the matrix with nano-sized carbides, even though the solid micron WC grains remain unchanged and firmly anchored in the cured matrix. This effect prevents wear of the specimen, resulting in better abrasion resistance.

As a result of tests nanostructured WC coating demonstrated improved wear resistance in the friction pair in comparison with conventional, but worsened in comparison with bimodal. In all coatings there is a typical mechanism of preferential wear of the cobalt matrix after separation of WC grains. Despite the lower microhardness than that of the nanostructured coating, the dissolution of nanostructured WC particles and the deposition of these nanostructured carbides in the spaces between micro-carbides avoids matrix wear during testing of the bimodal coating. The nanostructured and micro-carbide coatings exhibit approximately the same abrasive wear resistance, half that of the bimodal coating. The optimal combination of matrix-hardening nanoscale carbides and firmly anchored solid WC micrograin provides the tough surface required for improved wear resistance.

At the same time, studies have shown that large hardening particles are more resistant to abrasion by fine abrasives, since the main mechanism of material removal is preferential displacement of the binder followed by precipitation of carbide particles. The binder must be displaced to a shallow depth for nanoparticle precipitation of the hardening material to occur. Therefore, the wear rate of the nanoscale coating is higher than that of its conventional counterpart.

The size of carbide particles has a very strong influence on the impact wear resistance of composites. The smaller the size of the hardening particles, the better the impact wear resistance. It is best if the appropriate particle size is selected based on the operating conditions. This was confirmed by impact wear tests, where three different impact energies of 2.0; 3.5; and 5.0 J were selected. For comparison, wear tests were also carried out on 110Г13Л steel under the same conditions. All tests were conducted at an impact frequency of 1.5 blows/second, with a total number of 12000 blows. The abrasive medium was quartz sand with a particle size of 0.5-1.0 mm, a hardness of 1120 HV and a flow rate of 50 kg/h. During these tests, it was found that composites hardened with WC particles showed better impact wear resistance under low impact energy conditions. Composites hardened with fine WC particles show wear resistance slightly higher than that of 110Г13Л steel only at high impact energies. This is due to the fact that if the WC particles are small enough, the characteristic surface areas of the two phases become larger, and the interfacial area linking the WC particles and steel matrix becomes stronger, which leads to a reduced tendency of particles to fracture and spalling. However, the distance between the WC particles increases as their size increases, so that abrasives can penetrate the matrix much more easily, and the impact wear resistance of such composites is worse. Conversely, if the WC particle size is small, it is much more difficult for abrasives to penetrate the matrix, and the impact wear resistance of such composites is higher. Adhesion wear can also be reduced by increasing the carbide content without increasing the carbide size. Multi-modal carbide distribution may be a suitable tool for this purpose.

In order to solve problems related to the hardening of working surfaces, methods associated with the application of concentrated energy flows have recently been very actively used. Currently, significant progress has been achieved in the technology of cladding of products by vacuum electron-beam treatment. This technology allows to organize micrometallurgical process with minimal impact on the base metal. At the same time, it is possible to form a hardened layer, the thickness of which can be adjusted within wide limits.

To provide wear resistance in friction pairs it is necessary to solve the problem of rational choice of material of rubbing pairs and method of its processing. At a choice of a material, it is considered that criteria of its wear resistance depend not only on properties of a surface contact layer, but also properties of a volume of a material, conditions of its work. Operating conditions are so diverse that there is no universal wear-resistant material. A material that is resistant to wear in some conditions may catastrophically rapidly deteriorate in others. The wear resistance of a material under given friction conditions is usually determined experimentally.

Conclusions. In the overwhelming majority of cases composite materials and coatings are currently used as wear-resistant materials. The wear resistance of these materials depends on the structural-phase composition of the matrix and hardening particles. Therefore, it is necessary to develop optimal compositions of composite powders for electron-beam surfacing on the basis of molybdenum- and vanadium-doped manganese-covalent austenite, designed for hardening of working surfaces operating under conditions of shock-abrasive wear and low temperature.

As studies have shown, on the basis of combining the processes of cladding and aging in one cycle it is possible to obtain in the volume of the hardened layer a homogeneous disperse-hardened structure with multimodal size distribution of hardening phase particles. This makes it possible to provide an increase in the relative wear resistance coefficient of composite coatings based on manganese austenite by an average of 50% in comparison with only clad coatings.

The studies of formation of multimodal structure of coatings based on 11Р3АМФ2 steel are promising. Preliminary studies allow us to expect a sharp increase in abrasive wear resistance of these coatings. However, the question of the possible positive role of the volume fraction of residual austenite and secondary dispersed carbides in coatings based on 11Р3АМФ2 steel on the abrasive wear resistance under the action of abrasive of different hardness remains unclear. This is especially relevant in the light of the use of these coatings in the conditions of friction pairs for highly loaded products of aviation equipment.

In particular, the problem of rapid failure of pinion shafts due to intensive wear of nitrided bearing journals for needle bearings during several months of continuous operation arises in the operation of highly loaded gearboxes of aviation ground equipment. A design feature of these gearboxes is that their bearing journals act as the inner ring of the needle bearing. Therefore, further research should be directed to the establishment of interrelation of wear mechanisms of clad composite coatings based on 10Р6М5 steel with cladding modes, initial microstructure and its evolution under friction.

References

1. Barile, M.; Lecce, L.; Iannone, M.; Pappadà, S.; Roberti, P. Thermoplastic Composites for Aerospace Applications. In: Pantelakis S, Tserpes K (Ed.), Revolutionizing Aircraft Materials and Processes. Springer: 2020.

2. George, E. Totten. Handbook of Lubrication and Tribology: Volume I Application and Maintenance, Second Edition, 2006, 1159 pages.

3. Jia, K.; Fischer, T. Abrasion resistance of nanostructured and conventional cemented carbides. // Wear. - Release 200. - 1996. - c. 206-214.

4. Gee, M.; Roebuck. B.; Lindahl, P.; Andren, H. Constitutent phase nanoindentation of WC/Co and Ti(C,N) hard metals. Mater. Sci. Eng. A 1996, A209, 128-136.

5. Armstrong, R.; Cazacu, O. Indentation fracture mechanics toughness dependence on grain size and crack size: Application to alumina and WC-Co. Int. J. Refract. Met. Hard Mater. 2006, 24, 129-134.

6. J. Pirso, M.; Viljus, J.; Kubarsepp Slurry erosion-corrosion of TiC-NiMo cermets. // Slurry erosion-corrosion of TiC-NiMo cermets. - Vancouver, 1999. - c. 29-36.

7. Makhele-Lekala, L.; Luyckx, S.; Nabarro, F.R.N. Semi-empirical relationship between the hardness, grain size, and mean free path of WC-Co. Int. J. Refract. Met. Hard Mater. 2001, 19, 245-249.

8. Christensen, M.; Wahnstrom, G.; Lay, S.; Allibert, C.H. Morphology of WC grains in WC-Co alloys: Theoretical determination of grain shapes. Acta Mater. 2006, 55, 1515-1521.

9. Industrial Tribology: Tribosystems, Friction, Wear and Surface Engineering, Lubrication, Theo Mang, Kirsten Bobzin, Thorsten Bartels, 2010, 666 p.

10. Bogachev I.N., Korshunov L.G., Khadyev M.S. Study of hardening and structural transformations of 110Г13Л steel during friction // Physics of metals and metallurgy. - №43, - Issue 2. - 1977. - c. 380-387.

11. Zharov A.I., Rybalko F.P., Mikhalev M.S. On strain hardening of Hadfield steel // Physics of metals and metal science. - No. 38, - Issue 4. - 1974. - p. 1110-1112.

12. Filippov M.A., Zilberstein R.A., Lugovykh V.E. Phase transformations and strengthening of unstable austenitic steels under plastic deformation and shock loading // Metal science and thermal treatment of metals. - Issue 9. - 1981. - p. 38-40.

13. Livshits L.S., Platova S.N., Sokolova T.I. Behavior of steels with metastable austenite under conditions of gas abrasive wear // News of universities. Oil and gas. - Issue 4. - 1980. - p. 80-84.

14. Trtica M.S., Gakovic B.M., Nenadovic T.M., Mitrovic M.M. Surface modification of stainless steels by TEA CO_2 laser // Applied Surface Science. - Volume 177. - 2001. - c. 48-57.

15. D. Suh, S. Lee, Y. Koo, H.C. Lee Synthesizing a class "M" high speed steel on the surface of a plain steel. // Metallurgical and Materials Transactions. - Issue 27. - 1996. c. 3149.

16. X. Wu, G. Chen Nonequilibrium microstructures and their evolution in a Fe-Cr-W-Ni-C laser clad coating // Material Science and Engineering. – Volume 270. - 1999. - c. 183-189.

17. Golovchan, V.T. On the thermal residual microstresses in WC-Co hard metals. Int. J. Refract. Met. Hard Mater. 2007, 25, pp. 341-344.

18. Engineering tribology, G.W. Stachowiak, A.W. Batchelor, 2013, 883 p.

Oleksandr Anatoliyovych Tamargazin – Doctor of Technical Sciences, Professor, Professor of the Department of Airport Technologies, National Aviation University, 1 Lubomyra Huzar Ave., Kyiv, Ukraine, 03058, https://orcid.org/0000-0002-9941-3600

Liudmyla Borysivna Pryimak – Candidate of Technical Sciences, Associate Professor, Associate Professor of the Department of Airport Technologies, National Aviation University, 1 Lubomyra Huzar Ave., Kyiv, Ukraine, 03058, https://orcid.org/0000-0002-3354-9820

Illia Volodimirovich Morshch – PhD student of the Department of Airport Technologies, National Aviation University, 1 Lubomyra Huzar Ave., Kyiv, Ukraine, 03058, https://orcid.org/0000-0002-8517-7536

О.А. ТАМАРГАЗІН, Л.Б. ПРИЙМАК, І.В. МОРЩ

ОБҐРУНТУВАННЯ ДОЦІЛЬНОСТІ ВИКОРИСТАННЯ ІНСТРУМЕНТАЛЬНИХ ШВИДКОРІЖУЧИХ СТАЛЕЙ В ЯКОСТІ ПОКРИТТІВ У ВУЗЛАХ ТЕРТЯ

Проведено аналіз сучасних досліджень у галузі композиційних матеріалів на основі карбіду вольфраму які застосовуються у якості наплавочних матеріалів. Зокрема, проаналізовано вплив морфології карбідної фази на зносостійкість матеріалів. Особливу увагу приділено аналізу проведених досліджень ультрадрібно- і нанозернистих композиційних матеріалів, їх порівняльний аналіз із звичайними мікрозереними покриттями. Обґрунтовано доцільність дослідження застосування інструментальних швидкорізальних сталей як покриття, що наноситься методом вакуумної електронно-променевої обробки, що дозволяє організувати мікрометалургійний процес з мінімальним впливом на основний метал, та можливістю сформувати зміцнений шар, товщина якого регулюється в широких межах.

Ключові слова: композиційні матеріали, структурно-фазовий склад, працездатність, наплавка.

Список літератури

1. Barile, M.; Lecce, L.; Iannone, M.; Pappadà, S.; Roberti, P. Thermoplastic Composites for Aerospace Applications. In: Pantelakis S, Tserpes K (Ed.), Revolutionizing Aircraft Materials and Processes. Springer: 2020.

2. George, E. Totten. Handbook of Lubrication and Tribology: Volume I Application and Maintenance, Second Edition, 2006, 1159 pages.

3. Jia, K.; Fischer, T. Abrasion resistance of nanostructured and conventional cemented carbides. // Wear. - Release 200. - 1996. - с. 206-214.

4. Gee, M.; Roebuck. B.; Lindahl, P.; Andren, H. Constitutent phase nanoindentation of WC/Co and Ti(C,N) hard metals. Mater. Sci. Eng. A 1996, A209, 128-136.

5. Armstrong, R.; Cazacu, O. Indentation fracture mechanics toughness dependence on grain size and crack size: Application to alumina and WC-Co. Int. J. Refract. Met. Hard Mater. 2006, 24, 129-134.

6. J. Pirso, M.; Viljus, J.; Kubarsepp Slurry erosion-corrosion of TiC-NiMo cermets. // Slurry erosion-corrosion of TiC-NiMo cermets. - Vancouver, 1999. - с. 29-36.

7. Makhele-Lekala, L.; Luyckx, S.; Nabarro, F.R.N. Semi-empirical relationship between the hardness, grain size, and mean free path of WC-Co. Int. J. Refract. Met. Hard Mater. 2001, 19, 245-249.

8. Christensen, M.; Wahnstrom, G.; Lay, S.; Allibert, C.H. Morphology of WC grains in WC-Co alloys: Theoretical determination of grain shapes. Acta Mater. 2006, 55, 1515-1521.

9. Industrial Tribology: Tribosystems, Friction, Wear and Surface Engineering, Lubrication, Theo Mang, Kirsten Bobzin, Thorsten Bartels, 2010, 666 p.

10. Богачев И.Н., Коршунов Л.Г., Хадыев М.С. Исследование упрочнения и структурных превращений стали 110Г13Л при трении // Физика металлов и металловедение. - №43, - Выпуск 2. - 1977. - с. 380-387.

11. Жаров А.И., Рыбалко Ф.П., Михалев М.С. О деформационном упрочнении стали Гадфильда // Физика металлов и металловедение. - №38, - Выпуск 4. - 1974. - с. 1110-1112.

12. Филиппов М.А., Зильберштейн Р.А., Луговых В.Е. Фазовые превращения и упрочнение нестабильных аустенитных сталей при пластической деформации и ударном нагружении // Металловедение и термическая обработка металлов. - Выпуск 9. - 1981. - с. 38-40.

13. Лившиц Л.С., Платова С.Н., Соколова Т.И. Поведение сталей с метастабильным аустенитом в условиях газоабразивного изнашивания // Известия вузов. Нефть и газ. - Выпуск 4. - 1980. - с. 80-84.

14. Trtica M.S., Gakovic B.M., Nenadovic T.M., Mitrovic M.M. Surface modification of stainless steels by TEA CO_2 laser // Applied Surface Science. - Volume 177. - 2001. - c. 48-57.

15. D. Suh, S. Lee, Y. Koo, H.C. Lee Synthesizing a class "M" high speed steel on the surface of a plain steel. // Metallurgical and Materials Transactions. - Volume 27. - 1996. c. 3149.

16. X. Wu, G. Chen Nonequilibrium microstructures and their evolution in a Fe-Cr-W-Ni-C laser clad coating // Material Science and Engineering. – Volume - 1999. - c. 183-189.

17. Golovchan, V.T. On the thermal residual microstresses in WC-Co hard metals. Int. J. Refract. Met. Hard Mater. 2007, 25, pp. 341-344.

18. Engineering tribology, G.W. Stachowiak, A.W. Batchelor, 2013, 883 p.

Тамаргазін Олександр Анатолійович – докт. техн. наук, професор, професор кафедри технологій аеропортів Національний авіаційний університет, пр. Любомира Гузара, 1, м. Київ, Україна, 03058, https://orcid.org/0000-0002-9941-3600

Приймак Людмила Борисівна – канд. техн. наук, доцент, доцент кафедри технологій аеропортів Національний авіаційний університет, пр. Любомира Гузара, 1, м. Київ, Україна, 03058, https://orcid.org/0000-0002-3354-9820

Морщ Ілля Володимирович – аспірант кафедри технологій аеропортів Національний авіаційний університет, пр. Любомира Гузара, 1, м. Київ, Україна, 03058, https://orcid.org/0000-0002-8517-7536