UDC 621.891 (043.3) DOI: 10.18372/0370-2197.1(106).19827

O. TAMARGAZIN, L. PRYIMAK, I. MORSHCH

State University "Kyiv Aviation Institute", Ukraine

METHODOLOGICAL SUPPORT FOR RESEARCH ON THE FEASIBILITY OF USING HIGH-SPEED TOOL STEEL AS COATINGS IN FRICTION UNITS

The paper considers methods of research in the field of composite materials used as surfacing materials. In particular, the modern equipment used in the analysis of experimental samples obtained in the study of the use of tool high-speed steels as a coating applied by vacuum electron beam treatment in order to organize micrometallurgical processes with minimal impact on the base metal and the ability to form a hardened layer whose thickness is adjustable within wide limits is considered.

Key words: *composite materials, electron-beam surfacing, ion-electron microscope, interference microscope, profilometer.*

Introduction. The theory of contact interaction, which takes into account the wear of contacting bodies, is an effective means of calculating the wear of friction units, which largely determines their durability. To date, a number of analytical and numerical approaches to the solution of the wear-contact problem have been developed, which often involve complex mathematical apparatus and require significant computational resources. At the same time, methods based on experimental approaches are widely used to solve the wear-contact problem. In particular, for solving the problems posed in [1] the most effective will be precisely the experimental methods for investigating the effects caused by the peculiarities of wear of coatings based on high-speed steels.

Therefore, the purpose of this paper is to describe the subtleties of the methodological support of modern research in solving wear-contact problems, which were used in the study of coatings based on high-speed steels.

Setting of the task. In our research, we carried out cladding of me-tall on plates of the size 30×250 mm (the thickness of the substrate varied from 5 to 35 mm), made of steel 20. The width of the cladding track did not exceed 20 mm. To form the thickness of the clad layer ~2.5 mm, the number of passes of the electron beam was equal to four. To develop the mode of electron-beam cladding on shaft journals, model experiments on hardening of samples from steel 20Х3МВФ, previously normalized, which provided them with hardness at the level of 250-260 HB, were conducted.

Powder of 11Р3АМФ2 high-speed steel (Si - up to 0.5%, Mn - up to 0.5%, Ni < 0.4%, S < 0.03%, P < 0.03%, Cr - 3.8-4.3%, Mo - 2.5-3%, W - 2.5-3.3%, V - 2.3-2.7%, Co < 0.5%, N - 0.05-0.1%, Nb - 0.05-0.2%, Fe - ~84%), obtained by atomization of melt into water and composite powder "steel 11Р3АМФ2 + 20 weight. % WC" with a dispersity of 50-350 microns. Composite powder for cladding was obtained by mixing the above-mentioned powders, sintering the mixture in vacuum with subsequent crushing and sieving into fractions of the obtained sintered powders. The residual partial pressure in the chamber was not more than 10^{-2} Pa. The method of obtaining such composite powders is described in detail in [2].

Technological equipment for coating application. In our experiments, the electron-beam deposition unit was a vacuum automated system with computer control.

Fig. 1 shows the NexDep vacuum unit manufactured by Angstrom Engineering Inc., which was used for electron-beam deposition in our studies [2].

In particular, the part to be sprayed was loaded into the chamber and fixed inside on externally electrically driven rotation and displacement manipulators. A vacuum was created in the chamber by a vacuum station up to an operating pressure of 1^{-10} Pa. Scanning electron beam, formed by electron gun, hitting the surface of the part, forms a melt zone, into which powdered cladding material is fed by means of a doser. At a given speed of rotation and movement of the part on its surface is formed coating with the specified physical and chemical properties. All parameters of coating, rotation and movement are controlled by computer control. The electron beam gun is based on a reflective discharge source with a hollow cathode.

Figure 1. NexDep vacuum unit manufactured by Angstrom Engineering Inc. (Canada)

An important feature of the NexDep unit is that it is equipped with an electron gun with a plasma cathode. The use of such an electron source allowed to increase its lifetime and to perform cladding in technical vacuum (less than 0.5 Pa). To extract electrons from the plasma, a discharge with a high degree of inhomogeneity of concentration was used. This was necessary to reduce the thermal load on the electrodes and increase its efficiency. To initiate a discharge with a hollow cathode, an additional reflective discharge is used, which is a type of discharge in crossed electric and magnetic fields. Its main purpose is to ensure stable ignition and stable burning of the main discharge in the cathode cavity, as well as automatic initiation of the main discharge in the cathode cavity in case of its accidental extinguishment.

The NexDep unit was also additionally equipped with a powder feed system for the melt zone, consisting of a powder feeder with a hopper and a powder feeder control unit. Cladding of wear-resistant coating was carried out by feeding the cladding powder into the liquid-metal bath, which appears on the surface of the clad part under the action of the electron beam. Formation of wear-resistant coating occurs at combination of transverse vibrations of the electron beam and longitudinal movement of the part relative to the electron gun and powder feeder.

The parameters of the electron beam cladding process had the following characteristics:

– accelerating voltage – up to 30 kV
– beam current strength – up to 0.2 A
– discharge current strength – up to 1 A
– electron beam diameter – up to 1 mm
– sweep length – up to 29 mm
– substrate movement speed – 2.8 mm/sec
– duration of one cladding pass and time between passes – 90/90 s/sec.

At the same time the power of the electron beam at the preliminary pass was 200 W, at the first pass – 4150±100 W, at the second pass – 3050±100 W, at the third pass – 2200±100 W, at the fourth pass – 2050±50 W.

To estimate the temperature in the process of electro-beam cladding in the center, along the length of the workpiece from the base metal was introduced tungsten-rhenium thermocouple, located in close proximity to the surface of the clad metal thickness of 0.5 mm. The real temperature in the beam zone was much higher, but this integral temperature and its cooling rate with simultaneous analysis of thermo-kinetic curves of decomposition of supercooled austenite [3] allowed us to estimate the phase composition of the coating.

Methods of research. In our work we applied the traditional method of preparation of microdrills, which consisted in mechanical grinding and subsequent polishing on diamond pastes of different dispersity. Chemical etching of coatings was carried out in 4% alcoholic nitric acid solution. Quantitative characteristics of the microstructure (quantity, size, shape, distribution of different phases) were determined by the linear method of stereometric metallography [4].

The structure of the clad coatings before and after wear tests was examined using an optical microscope Magus Metal V790 DIC (Fig. 2).

Figure 2. Magus Metal V790 DIC optical microscope

In addition, a Hitachi SU7000 scanning electron microscope (Fig. 3) equipped with a large sample chamber with 18 ports for installation of all possible analytical attachments was used in the studies, allowing to examine samples up to 200 mm in diameter [5]. The electron-optical scheme of the microscope is unique in its kind and consists of an electron booster, a three-condenser lens, and a hybrid electromagnetic-electrostatic non-dimensional objective lens. The most important advantage of the SU7000 microscope is its extensive detection system: an Everhart-Thornley detector, two scintillator detectors in the column operating even in low vacuum and at low accelerating voltages, a UVD secondary electron detector in low vacuum used for cathodoluminescence detection. In addition, the microscope is equipped with a STEM detector, a photodiode BSE detector, and five EDX attachments. Images were captured in ultra-high resolution at 10240×7680 pixels. One image is enough to analyze hundreds to thousands of particles.

Quanta 200 3D Dual Beam SEM ion-electron microscope (Fig. 4) capable of obtaining surface images with a resolution of ~1 nm was also used. This instrument is a system capable of imaging and micromachining. The instrument is capable of obtaining a resolution of 1.2 nm at 30 kV with an SE detector. The resolution of the FIB is 5-7 nm. The Ga ion source has an accelerating voltage from 2 kV to 30 kV and the ESEM resolution is 1.5 nm.

Figure 3. Hitachi SU7000 scanning electron microscope

Figure 4. Ion electron microscope Quanta 200 3D Dual Beam SEM

Cross sections with respect to the friction surface of ~10×10×5 μm for use in Quanta 200 3D were produced by atomizing the material with a focused ion beam at an accelerating voltage of 30 kV. The cross-sectional images were obtained with the sample tilted at 55 degrees. The signal of secondary and backscattered electrons was used [6]. The chemical composition in the local region was analyzed by micro-X-ray spectral analysis using the EDAX Genesis 2000 XMS 30 system (FEI).

Studies of the phase composition of the initial coating, after its abrasive wear tests and friction tracks after friction pair tests were carried out by means of X-ray diffraction analysis on a multifunctional X-ray diffractometer Bruker D8 Discover (Fig. 5) in the range of angles 5-120° with a step of 0.05°. The diffractometer software was used for quantitative phase analysis.

Figure 5. Bruker D8 Discover multifunctional X-ray diffractometer

Evaluation of surface roughness parameters after wear tests was carried out on a ZYGO NewView 7300 scanning interference microscope (Fig. 6).

Surface roughness parameters after the tests were evaluated on a LUPHOScan 50 SL Non-contact 3D 3D profilometer (Fig. 7) on a 25 mm long section. In particular, the Gauss’ filter was applied for data processing.

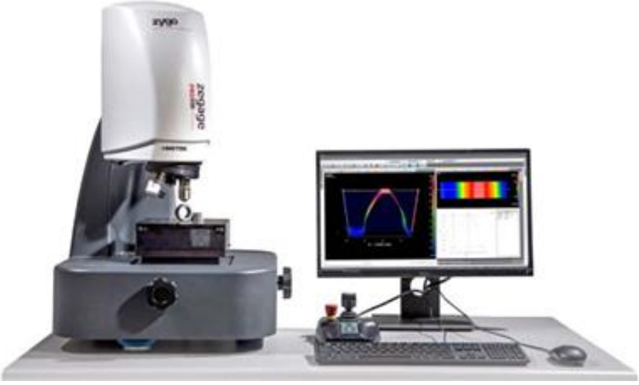

Figure 6. ZYGO NewView 7300 scanning interference microscope

Figure 7. LUPHOScan 50 SL Non-contact 3D profilometer

Microhardness on transverse and oblique sections was determined on a ПМТ-3 device at a load of 0,98 N with a depth step of 100 μm. Microhardness was measured on two tracks, which made it possible to plot Hμ-L dependence after 50 μm, and on oblique sections – after 10-15 μm.

The microhardness (HV) of the shaft coatings and the base metal (substrate) immediately adjacent to the cladding was measured on an HVS1000 device with a depth step of 100 μm at a load of 200 and 500 grams.

To determine the abrasive wear resistance used the method of "Testing of materials for abrasive wear when rubbing against not rigidly fixed abrasive particles" ДСТУ 23.208-79. Steel 45 in the annealed state with hardness 190-200 HV was used as reference samples. Relative wear resistance of the studied claddings was calculated by the formula:

$$K_r = (g_r \times \rho_i)/(g_и \times \rho_э),$$

where ρ_r and ρ_i – densities of reference and investigated materials, g/cm^3; g_r and g_i – values of weight loss during tests of reference samples and samples of investigated material. Quartz sand and electrocorundum were used as abrasives. The average size of the abrasive particles did not change after the wear tests and left ~200 μm. The specimen was worn with the abrasive entrained by a rubber roller on the friction surface. The essence of the technique is to measure the mass loss of the test specimen (g_i) after five test cycles (the test cycle included wear of the specimen for one hour) and compare it with the g_r of a reference. Material test conditions for wear against non-rigidly bonded abrasives were given under the following conditions:

– specimen size – 20×25×7 mm;
– rubber roller dimensions:
– diameter 48-50 mm;
– width 15 mm;
– properties of the rubber roller:
– hardness according to ДСТУ 263-75 – 78-85;
– relative residual elongation of the material according to ДСТУ 270-75 – 15-20%;
– roller rotation frequency – 60 rpm;
– load on the sample – 44,1±0,25 H.

Friction tests were carried out on the Universal testing machine WDS series Jinan Hensgrand Instrument Co., Ltd (Fig. 8) using the scheme “wheel – two flat pads” at stepwise increase of speed (1.2; 2.4 and 3.6 m/s) and load (20, 40, 60, 80 and 100 N) under friction conditions without lubrication. Initial samples with dimensions 10×10×5 mm with coating were cut from massive previously clad blanks by electroerosion method. The thickness of the coating is 2 mm. The surface of the coating before testing was polished on diamond pastes of different dispersity.

Fig. 8. Universal testing machine WDS series Jinan Hensgrand Instrument Co., Ltd.

The counterbody was a wheel with a diameter of 62 mm and width of 15 mm, made of hardened steel ШХ15СГ (HRC 63-65). After the friction pair development at each fixed speed and load four experiments with the friction path at a distance of 2000 m were conducted irrespective of the counterbody rotation speed. The ratio of the volume of material lost by the specimens during the test to the friction distance (mm^3/km) was used as a measure of wear intensity.

Conclusions. To date, friction in many of its aspects remains unclear. At friction simultaneously occur mechanical, electrical, thermal, vibration, chemical and other processes. Friction may cause hardening or de-hardening of metals, change of chemical composition and other phenomena. All this requires research with the use of the most modern devices and machines. In particular, the considered methods and equipment allowed us to study the influence of the thickness of the base metal samples made of low-carbon steel on the structural-phase composition of the hardened layer at multi-pass electron-beam cladding with 11Р3АМФ2 steel powder. And also, to carry out tests on abrasive wear (quartz sand and electrocorundum) and to estimate the role of residual metastable austenite and the presence of dispersed secondary carbides in increasing the wear resistance of coatings based on steel 11Р3АМФ2.

References

1. Tamargazin, O.; Pryimak, L.; Morshch, I. Substantiation of Expediency of Use of Tool High-Speed Cutting Steels as Coatings in Friction Units / Проблеми тертя та зношування, 2024, 1(102), С. 4-13, DOI: 10.18372/2310-5461.61.18515

2. Shuili Gong, Jianrong Liu, Guang Yang, Haiying Xu Electron Beam Wire Deposition Technology and Its Application, Springer, National Defense Industry Press, 2022, 312 pp.

3. Jimei, Xiao ed. Alloying phase and phase transformation (Second ed.), Beijing: Metallurgy industry Publisher, 2004

4. John F. Watts, John Wolstenholme an Introduction to Surface Analysis by XPS and AES, 2003, 224 pp.

5. Rik Brydson Abberation-Corrected Analytical Transmission Electron Microscopy, 2011, 280 pp.

6. Raghavan V. Physical Metallurgy: Principles and Practice, 2015, 260 pp.

Стаття надійшла до редакції 16.01.2025.

Oleksandr Anatoliyovych Tamargazin – Doctor of Technical Sciences, Professor, Professor of the Department of Airport Technologies, State University "Kyiv Aviation Institute", 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, State University "Kyiv Aviation Institute", 1 Lubomyra Huzar Ave., Kyiv, Ukraine, 03058, https://orcid.org/0000-0002-3354-9820

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

Тамаргазін Олександр Анатолійович – докт. техн. наук, професор, професор кафедри технологій аеропортів ДНП «ДУ «КАІ», пр. Любомира Гузара, 1, м. Київ, Україна, 03058, oleksandr.tamarhazin@npp.nau.edu.ua, https://orcid.org/0000-0002-9941-3600

Приймак Людмила Борисівна – канд. техн. наук, доцент, доцент кафедри технологій аеропортів ДНП «ДУ «КАІ», пр. Любомира Гузара, 1, м. Київ, Україна, 03058, https://orcid.org/0000-0002-3354-9820

Морщ Ілля Володимирович – аспірант кафедри технологій аеропортів ДНП «ДУ «КАІ», пр. Любомира Гузара, 1, м. Київ, Україна, 03058, https://orcid.org/0000-0002-8517-7536

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

МЕТОДИЧНЕ ЗАБЕЗПЕЧЕННЯ ДОСЛІДЖЕНЬ ДОЦІЛЬНОСТІ ВИКОРИСТАННЯ ІНСТРУМЕНТАЛЬНОЇ ШВИДКІСНОЇ СТАЛІ У ЯКОСТІ ПОКРИТТІВ У ВУЗЛАХ ТЕРТЯ

Дослідження технологій поєднання процесів наплавлення і старіння в одному циклі дозволяє отримати в об'ємі зміцненого шару однорідну дисперсійно-зміцнену структуру з мультимодальним розподілом частинок збіднюючої фази. Це дозволяє забезпечити збільшення коефіцієнта відносної зносостійкості композиційних покриттів на основі марганцевистого аустеніту в середньому на 50% порівняно з тільки наплавленими покриттями. Було встановлено, що зносостійкість цих матеріалів залежить саме від структурно-фазового складу матриці та зміцнювальних частинок, тому були розглянуті методи проведення таких досліджень з розробки оптимального складу композиційних порошків для електронно-променевого наплавлення на основі легованого молібденом і ванадієм марганцевистого аустеніту. Зокрема, було розглянуто сучасне обладнання, яке використовується при аналізі експериментальних зразків отриманих при дослідженні застосування інструментальних швидкорізальних сталей як покриття, що наноситься методом вакуумної електронно-променевої обробки, з метою організації мікрометалургійних процес з мінімальним впливом на основний метал, та можливістю сформувати зміцнений шар, товщина якого регулюється в широких межах.

Ключові слова: композиційні матеріали, електронно-променева наплавка, іонно-електронний мікроскоп, інтерференційний мікроскоп, профілометр

Список літератури

1. Tamargazin, O.; Pryimak, L.; Morshch, I. Substantiation of Expediency of Use of Tool High-Speed Cutting Steels as Coatings in Friction Units / Проблеми тертя та зношування, 2024, 1(102), C. 4-13, DOI: 10.18372/2310-5461.61.18515

2. Shuili Gong, Jianrong Liu, Guang Yang, Haiying Xu Electron Beam Wire Deposition Technology and Its Application, Springer, National Defense Industry Press, 2022, 312 pp.

3. Jimei, Xiao ed. Alloying phase and phase transformation (Second ed.), Beijing: Metallurgy industry Publisher, 2004

4. John F. Watts, John Wolstenholme an Introduction to Surface Analysis by XPS and AES, 2003, 224 pp.

5. Rik Brydson Abberation-Corrected Analytical Transmission Electron Microscopy, 2011, 280 pp.

6. Raghavan V. Physical Metallurgy: Principles and Practice, 2015, 260 pp.