σkr=14.15<σdop=160 MPa

The vibration load of the sieve is calculated based on the following parameters: sieve mass m=10 kg; vibration amplitude xmax=0.005 m; suspension stiffness k=5000 N/m

Then the force from the oscillation:

F=k · xmax=5000 · 0.005=25 N

Stress at the center of the plate (fine sieve, formula for a rectangular plate):

$$\sigma_{\text{sieve}} = \frac{3FL^2}{2bh^2} = \frac{3\cdot 25\cdot 0.6^2}{2\cdot 0.3\cdot 0.005^2} = 1.8\cdot 106\,\text{Па} = 1.8\,\text{М}Pa \tag{7}$$

Check: σsieve=1.8<σadd=160 MPa

The practical value of the work lies in the possibility of using the obtained results in the design of new and modernization of existing seed separators. Substantiated design parameters will ensure a reduction in the stress level in the most loaded sections by 15–25%, which will accordingly increase the service life of the machine and increase the reliability of the technological process of selecting cucumber and melon seeds.

It is advisable to direct further research towards experimental verification of calculation models by strain gage testing and assessment of the fatigue strength of structural elements under cyclic loading conditions.

References:

1. Wu, Y., et al. (2024). Simulation analysis and parameter optimization of seed–flesh separation process based on DEM. Agriculture, 14(7), 1008. https://doi.org/10.3390/agriculture14071008.

2. Ahmed, A., Zhang, Z., Manzoor, SH, Abdelhamid, MA, & Gul, N. (2026). Cucumber picking robots: Technological progress, challenges, and future directions. Smart Agricultural Technology, 13, 101813. https://doi.org/10.1016/j.atech.2026.101813.

3. Babenko, D., Dotsenko, N., Gorbenko, O., & Kim, N. (2021). Justification of the introduction of a seed separator for vegetable and tomato crops as part of a technological line. Ukrainian Black Sea Region Agrarian Science, 25(2), 80-87. https://doi.org/10.31521/2313-092X/2021-2(110)-10.

4. Babenko, D.V., Dotsenko N.A., Gorbenko, O.A. (2023). Mechanics of materials and structures. Part 2: practical training based on interactive graphic and digital content: a textbook. Mykolaiv: MNAU, 2021. 176 p.

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IMPROVING THE RELIABILITY OF AGRICULTURAL MACHINERY PARTS BY FORMING NANOSTRUCTURED ELECTRIC ARC COATINGS

ПІДВИЩЕННЯ НАДІЙНОСТІ ДЕТАЛЕЙ СІЛЬСЬКОГОСПОДАРСЬКОЇ ТЕХНІКИ ФОРМУВАННЯМ НАНОСТРУКТУРОВАНИХ ЕЛЕКТРОДУГОВИХ ПОКРИТТІВ

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Introduction. Modern agricultural production is characterized by a high intensity of machinery operation, which leads to accelerated wear of working surfaces of components. Tillage, seeding, and harvesting machines are in constant contact with abrasive particles, subjected to impact-cyclic loads, and exposed to corrosive effects of aggressive environments. The primary cause of failure of agricultural machinery is precisely the surface degradation of components, resulting in significant costs for repairs and the procurement of spare parts.

One effective method for restoring and strengthening such components is thermal spraying, specifically the electric arc method. Its advantages include relative cost-effectiveness, high productivity, and minimal thermal impact on the base material of the component. However, conventional electric arc coatings do not always provide the required level of physico-mechanical properties, such as hardness, adhesion strength, and, consequently, wear resistance. Therefore, the search for technological solutions to enhance the performance characteristics of coatings, particularly by forming nanoscale elements within their structure capable of providing a significant increase in strength, is of high relevance.

A promising approach to nanostructuring thermal spray coatings is the application of pre-recrystallization heat treatment (PRHT). This method involves short-term heating of the as-sprayed coating to temperatures below the recrystallization temperature, which initiates polygonization processes and the formation of a refined substructure without altering the overall morphology of the coating. Unlike other nanostructuring methods (e.g., using agglomerated nanopowders, suspension spraying), PRHT does not require complex and expensive preparation of initial materials, is technologically simple, and can be easily integrated into existing technological processes for component restoration. Furthermore, the formation of functional composite coatings is ensured through the use of metallic materials and fillers [1] or clad powders [2]. In studies [3, 4], a method based on the use of a modified spray gun and a free-standing reinforcing phase powder for coating formation was proposed. Using this method, metal-polymer [3], as well as metal-ceramic and metal-carbide composite coatings [4], were obtained.

Objective. Investigation of the influence of temperature-time parameters of pre-recrystallization heat treatment on the level of physico-mechanical properties of composite electric arc coatings of the Sv-08G2S – Al_2O_3 and 65G – TiC systems, formed using the reinforcing phase powder in free form, and substantiation of the feasibility of applying this approach to enhance the reliability of agricultural machinery components.

Materials and Methods. The objects of study were electric arc metal-ceramic coatings of the Sv-08G2S wire – aluminum oxide (Al_2O_3) composition and metal-carbide coatings of the 65G wire – titanium carbide (TiC) composition. A KDM-2 electric arc spraying set, equipped with a modernized EM-14M spray gun incorporating a unit for feeding the reinforcing phase powder into the high-temperature zone of the arc discharge, was used to form the coatings. The optimal deposition parameters were: current – 120 A, arc voltage – 30 V, spraying distance – 80 mm, compressed air pressure – 0.4…0.6 MPa. The content of the reinforcing phase in the coatings was: TiC – 18.5%, Al_2O_3 – 8.7%. The coating thickness was 0.5…1.0 mm.

Pre-recrystallization heat treatment of the samples was carried out in a SNOL-1.6.2.0.08/9-M1 laboratory electric furnace. Microhardness measurements of the metal matrix were performed using a PMT-3 microhardness tester at an indenter load of 100 g in accordance with DSTU ISO 6507-4:2008. Structural changes were investigated by X-ray diffraction analysis using a DRON-3 diffractometer. The size of coherent scattering regions (CSR) was determined using the Scherrer formula and the harmonic analysis method. Metallographic studies were conducted on a REMMA 102-02 scanning electron microscope-microanalyzer and a ZEISS Gemini SEM 500. The adhesion strength of the coatings to the substrate was determined using a UMM-5 tensile testing machine by the "pin method".

Results and discussion. At the first stage of the research, the optimal temperature-time parameters of pre-recrystallization heat treatment for conventional unreinforced coatings, which constitute the metallic matrix of the composites, were established. For the coating produced from Sv-08G2S wire, the optimal regime is a temperature of 450 °C with a holding time of 2 minutes, which provides an increase in Vickers hardness of 40% and a reduction in CSR size to 62 nm. For the coating from 65G wire, the following optimal regime was determined: temperature of 400 °C, holding time of 3 minutes, hardness increase of 26%, CSR size of approximately 100 nm. The dependence of hardness on temperature and holding time exhibits an extreme nature, which is explained by the competition between polygonization (hardening) and incipient recrystallization (softening) processes.

For composite coatings containing a reinforcing phase, the optimal PRHT regimes were adjusted. The microhardness of the metal matrix after spraying of the Sv-08G2S – Al_2O_3 composite was 1.6 GPa; for 65G – TiC, it was 2.6 GPa. It was established that for the Sv-08G2S – Al_2O_3 coating, the optimal regime is a holding time of 1 minute at a temperature of 450 °C, and for the 65G – TiC coating – 2 minutes at a temperature of 400 °C. Under these regimes, the maximum increase in microhardness of the metallic matrix is observed: 54% (up to 2.46 GPa) and 38% (up to 3.59 GPa), respectively.

The more pronounced hardening effect of composite coatings compared to unreinforced ones after PRHT is attributed to the additional strain hardening of the metal matrix by high-velocity hard particles of Al_2O_3 and TiC. These particles, colliding with the forming surface, create local plastic deformation zones, thereby increasing the density of crystal lattice defects. During subsequent heat treatment, these defects become nucleation sites for new subgrains, ensuring a more effective structure refinement compared to pure metal.

Metallographic studies revealed that composite coatings exhibit a typical lamellar structure, with well-differentiated particles of the dispersed reinforcing phase (Al_2O_3, TiC) appearing darker. After PRHT, no microstructural changes are observed at the micro-level, and porosity remains at the same level (approximately 8% and 5%, respectively). This indicates that the hardening effect is achieved precisely through the internal rearrangement of the metallic matrix substructure, rather than through a reduction in coating defectiveness.

X-ray diffraction analysis confirmed the formation of nanoscale substructural elements after PRHT. Diffractograms clearly show a broadening of diffraction maxima, which is associated with the refinement of structural elements, as the effect of internal stresses decreases upon heating. Determination of CSR size using the Scherrer formula and harmonic analysis showed a reduction of this characteristic to the level of 100 nm, allowing the resulting structure to be classified as nanocrystalline.

Experimental studies of adhesion strength have established that PRHT under optimal regimes provides an increase in this parameter by 15–20% compared to as-sprayed coatings. This is explained by the reduction of residual internal stresses in the coating, which arise during high-velocity particle deposition. Partial stress relaxation upon heating improves the adhesive interaction at the coating-substrate interface.

Conclusions. The conducted research has shown that pre-recrystallization heat treatment is an effective and technologically simple method for enhancing the physico-mechanical properties of composite electric arc coatings. The optimal regimes are as follows: for the Sv-08G2S – Al_2O_3 coating – temperature of 450 °C, holding time of 1 minute; for the 65G – TiC coating – temperature of 400 °C, holding time of 2 minutes. These regimes provide an increase in the microhardness of the metallic matrix by 38–54% and in adhesion strength by 15–20% due to the formation of a nanoscale substructure (CSR size ~100 nm).

The obtained results allow recommending the application of PRHT to composite electric arc coatings for the restoration and strengthening of agricultural machinery components operating under conditions of intensive abrasive wear (ploughshares, cultivator points, seeder working elements, mower blades, etc.). The increase in hardness and adhesion strength will ensure an extended service life of components, reduced machinery downtime, and lower repair costs, collectively providing a significant economic benefit for agricultural producers. Further research will be directed towards studying the effect of PRHT on the operational wear resistance of coatings under real-world agricultural production conditions.

References

1. Mal’tseva S. V., Mel’nikova I.P., Lyasnikova A. V., Zaharevich A.M. Structure and properties of modified plasma-sprayed composite coatings on a titanium base. *Mechanics of Composite Materials*. 2016. Vol. 52. P. 531 – 534. doi:10.1007/s11029-016-9603-2.

2. Borisov Y.S., Borisova A.L., Kolomytsev M.V. High-Velocity Air Plasma Spraying of (Ti, Cr)C–32 wt.% Ni Clad Powder. *Powder Metallurgy and Metal Ceramics*. 2017. Vol.56. P.305 – 315. doi:10.1007/s11106-017-9898-0.

3. Карпеченко А.А., Бобров М.М., Лимар О.О. Електродугове напилення композиційних металополімерних покриттів *Вісник Вінницького політехнічного інституту*. 2021. № 2. С. 114 – 119. doi:10.31649/1997-9266-2021-155-2-114-119.

4. Карпеченко А. А., Бобров М. М., Дубовий О. М., Макруха Т. О., Неделько Є. Ю. Формування композиційних металокерамічних та металокарбідних електродугових покриттів. *Вісник Національного технічного університету « ХПІ», Серія: Нові рішення в сучасних технологіях. Харків: НТУ «ХПІ»*. 2021. № 1 (7). С. 9-17. doi:10.20998/2413-4295.2021.01.02