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Establishing optimal parameters for resistance welding of agricultural machinery shafts

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Abstract

This paper searches for optimal values of resistance welding parameters of composite wires to increase the durability of agricultural machinery shafts. The optimization parameter was chosen to be the adhesion strength of the composite coating to the base of the part. The adhesion of the composite coating to the base material was evaluated using the normal tear method. To determine the optimal modes of applying composite coatings, an active experiment was conducted using mathematical planning methods. The obtained response surfaces and graphs of equal yield lines made it possible to establish the influence level of the research factors on the optimization parameter. To analyze the influence of factors on the optimization criterion, scatter graphs with histograms were constructed, which allows to graphically determine the rational values of the selected optimization criterion – the adhesion strength of the composite coating to the base during resistance welding of composite wires. The implementation of the central composite plan 2^{5-2} made it possible to establish the influence of the resistance welding parameters of composite wires (welding current strength; pressure on the electrodes; duration of the current pulse and pause; linear speed of the part rotation) on the adhesion strength of composite coatings to the base and determine their rational values.

Key words: resistance welding, composite coating, adhesion strength, agricultural machine shafts, optimal parameters.

Introduction

The technical condition of agricultural machines largely depends on the technical condition of their friction units. But today, there are still friction units of agricultural machines that are not sufficiently adapted to real operating conditions. This is evidenced by the fact that the service life of, for example, shafts is significantly lower than the service life of the machine as a whole [1]. Therefore, to increase the service life of agricultural machinery, it is advisable to increase the durability of shafts. One of the ways to solve this problem is to use technological methods to increase the wear resistance of parts [2]. Paper [3] proved the feasibility and effectiveness of using resistance welding when applying composite ceramic-metal coatings to the working surface of agricultural machinery shafts operating under abrasive wear.

For the restoration of cylindrical surfaces, various methods of surfacing, gas-flame and plasma spraying, electrolytic deposition, and resistance welding are mainly used [4]. Wide opportunities for increasing the durability of parts are opened up by the use of resistance welding and powder brazing, which has the following undeniable advantages [5]: high productivity; minimal losses of filler material (during welding and subsequent processing, losses do not exceed 5%); practically no burnout of chemical elements of the filler material; insignificant thermal effect on the part (the zone of thermal influence does not exceed 0.3 mm); the ability to apply a thin, dense, pore- and shell-free layer of metal with high hardness and with minimal allowance for machining.

Literature review

Resistance welding is carried out on special installations by joint deformation of the welding material and the surface layer of the base metal, heated at the place of deformation to a plastic state by short (0.02...0.5 s) current pulses of 5...30 kA [6]. Depending on the type and shape of the filler material, there are resistance welding of compact (tape, wire), powder (granular), and combined materials.

In order to achieve high wear resistance of the restored shafts, coatings that work well under abrasive wear conditions are needed. In this case, preference should be given to composite coatings [7]. Studies [8] state that the method of resistance welding using composite wire has wide technological capabilities and provides obtaining composite coatings with the achievement of the required performance properties of parts.

One of the main operational properties that determine the durability of parts with composite coatings, applied by resistance welding of composite wire in particular, is their adhesion strength to the base metal, which in turn depends on the modes of forming the composite coating.

From this point of view, it is quite reasonable to study the effect of resistance welding parameters on the adhesion strength of the composite coating with the base.

Paper [9] presents a methodology for optimizing technologies for coating application according to the strength and wear resistance criteria, which ensure the maximum possible strength and durability of the part with a coating at minimal cost for the coating application process. The prospects of using the optimization direction by the method of experiment factorial planning have been convincingly proven on such technologies as gas-flame and detonation spraying [10], vacuum plasma spraying [11], electric spark alloying [12], ionic nitriding [13], and finishing antifriction non-abrasive treatment [14, 15].

Purpose

The purpose of the presented research is to establish rational values for the parameters of resistance welding of composite coatings in order to increase the strength of their adhesion to the base.

Research Methodology

In most cases, the performance of agricultural machinery parts restored by resistance welding is determined by the adhesion strength of the applied coating to the base. Therefore, this indicator should be chosen as the optimization criterion. It should be noted that the adhesion strength of composite coatings to the base largely depends on the modes of resistance welding.

Experimental studies of the resistance welding of composite wires were carried out on the installation 011-1-02N. The following main parameters were monitored in the process of resistance welding of composite coatings: applied pressure value; electric current strength, current pulse duration and pause between pulses; part rotation speed and welding head feed rate.

The most technologically advanced materials for resistance welding of composite coatings are composite wires, which represent a sheath filled with the necessary components in the form of a powder. In the course of the study, the sheath material used was steel 08 ps, the chemical composition of which is shown in Table 1.

Table 1

Chemical composition of steel 08 ps, % [16]

Brand	Fe	C	Mn	Si	Cr	S	P	Cu	N	As
					no more than					
Steel 08ps	Base	0.05-0.11	0.35-0.65	0.05-0.17	0.10	0.04	0.035	0.25	0.25	0.08

The main material of the matrix is iron – PZhV-5 powder (Table 2), an inexpensive material with high welding properties.

Table 2

Chemical composition of iron powder PZhV-5, % [16]

Brand	Fe	C	Si	Mn	S	P	O	Residue insoluble in HCl
PZhV 5	Base	0,25	0,30	0,50	0,05	0,05	2,0	0,6
C	Si	Mn	Ni	S	P	Cr	Cu	Fe
0.27 - 0.34	0.9 - 1.2	1.0 - 1.3	1.4 - 1.8	≥ 0.025	≥ 0.025	0.9 - 1.2	≥ 0.3	~94

Composite powders were used in the core of the welded flux-cored wires: nickel-clad ceramics, which improves the thermal and electrophysical characteristics of the composite coating. Chromium carbide was used as filler.

Thus, a wire with a diameter of 2 mm was made for the study, the microstructure of which is shown in Fig. 1.

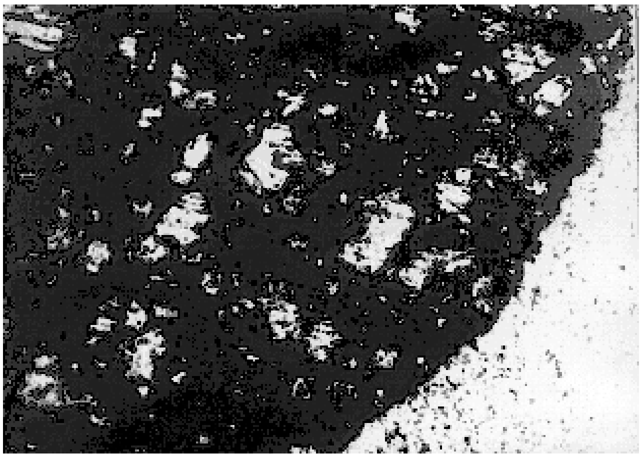


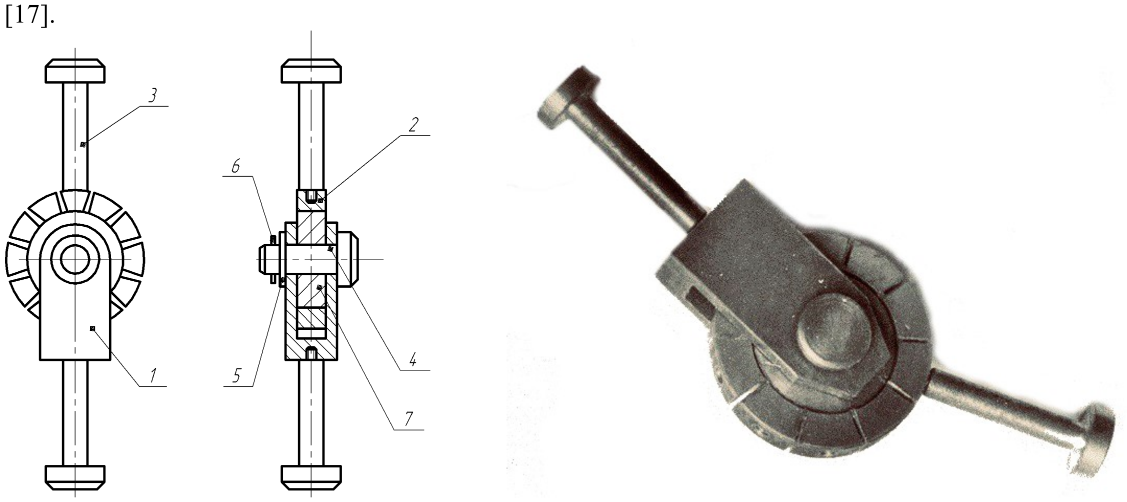
Fig. 1. Microstructure of flux-cored wire, ×100 % [16]

The resistance welding of composite wires of the specified composition was carried out on samples made of steel 50, which is widely used for the manufacture of agricultural machinery shafts.

To determine the optimal modes of composite coatings application, an active experiment was conducted using mathematical planning methods.

Since the optimization parameter is the adhesion strength of the composite coating to the base, the choice of the methodology for its evaluation deserves special attention.

The evaluation of the composite coating adhesion to the base material was carried out by the normal tear method using a special device developed by the authors, the scheme and general view of which are shown in Fig. 2 [17].



a) b)

Fig. 2. Scheme (a) and general view (b) of a device for determining the adhesion strength of a composite coating to a base metal: 1 – fork; 2 – split bushing; 3 – clamps; 4 – axis; 5 – washer; 6 – cotter pin; 7 – sample [17]

In accordance with the proposed methodology [17], a bushing 2 (Fig. 2), previously cut into sectors, each with threaded holes for screwing the clamp 3, was glued to the outer surface of the sample 7, which was studied with a composite coating. After polymerization of the glue, the cuts made on the bushing were deepened to the surface of the base metal. The sample with the glued sectors was mounted on the axis in the fork 1 of the device. The clamps were screwed into the threaded holes of the fork and the sector to be torn off. The sectors were torn off using a tensile machine MP-500, and the adhesive stress was calculated using the formula:

$$\sigma_{ad} = \frac{P}{F},$$

where P – tearing force, N; F – area of the sector inner surface, m^2.

To determine the optimal modes of composite coatings application, an active experiment was conducted using mathematical planning methods.

The purpose of the experiment series was to implement the central composite plan 2^{5-2}, which resulted in the determination of a number of factors influence (welding current; electrode pressure; current pulse duration; pause duration; linear rotation speed of the part) on the adhesion strength of composite coatings to the base.

The rotational plan has five levels: top, zero, bottom, and two outer levels (“star points”). The interval from the zero level to the “star points” is defined by the “star shoulder” equal to 1.68 [18]. In order to prevent the influence of systematic errors caused by unconsidered factors, the experiments were conducted in a random order, for which a table of random numbers was used.

The experimental data were processed using the STATISTICA 12.0 software package.

Results

The resulting regression equation is as follows:

$$Y = 144{,}983 + 22{,}066x_1 + 16.693x_2 + 18.193x_3 - 3.14x_4 - 0.779x_5 - -25.563x_1^2 -$$
$$-7{,}127x_2^2 - 2{,}327x_3^2 - 2{,}615x_4^2 - 2.065x_5^2 + +7.023x_1x_2 + 4.948x_1x_3 - 11.04x_1x_4 + 10.319x_1x_5 -$$
$$-0{,}652x_2x_3 - 5{,}715x_2x_4 + 9.544x_2x_4 + 2.91x_3x_4 - 0.68x_3x_5 + 9.057x_4x_5$$

where x_1 – welding current strength, kA;
x_2 – pressure on the electrodes, MPa;
x_3 – duration of the current pulse, s;
x_4 – pause duration, s;
x_5 – linear speed of part rotation, m/s.

The statistical evaluation of the obtained results allows considering the experiments to be equally accurate. The significance of the obtained coefficients was checked using the Student's criterion, and the adequacy of the equations – using the Fisher's criterion.

The analysis of the Pareto Chart (Fig. 3) and the tabular results of the experiment revealed that the following factors have the greatest influence on the adhesion strength: x_1, x_3, x_2 and the quadratic function of x_1 and x_2.

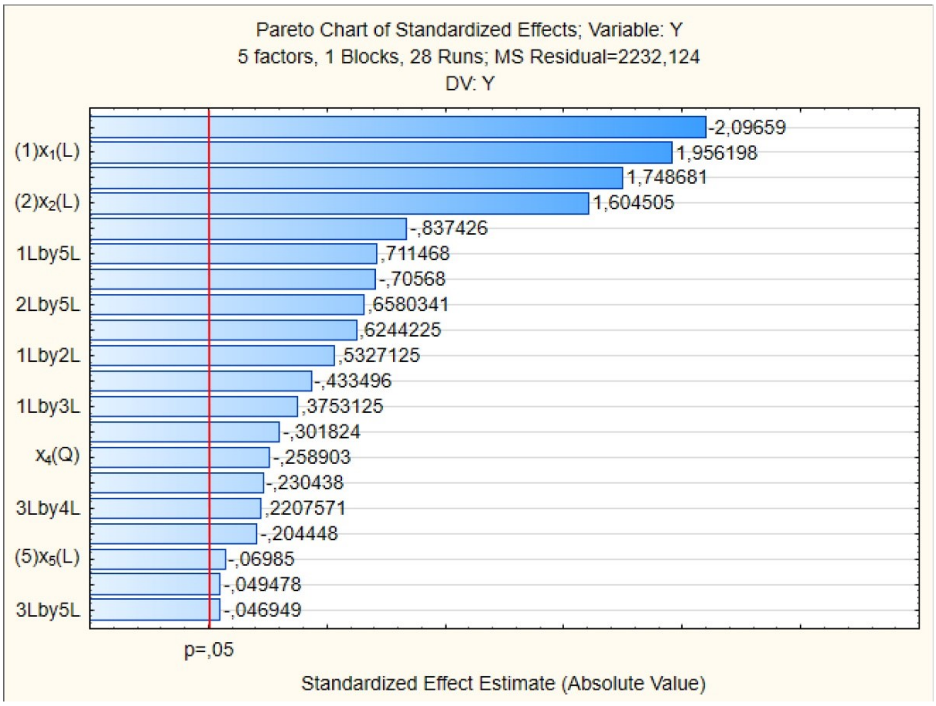


Fig. 3. Standardized Pareto Chart for adhesion strength

The response surfaces and graphs of equal yield lines (Fig. 4) make it possible to note that the highest adhesion strength of composite coatings to the base occurs at the following values of the factors: x_1 = 14.8…15.2 kA; x_2 = 0.3…0.4 MPa; x_3 = 0.06…0.08 s; x_4 = 0.05…0.06 s; x_5 = 0.018…0.02 m/s.

To analyze the influence of the factor on the optimization criteria, we constructed experimental scatter graphs with histograms (Fig. 5), which allows to graphically determining the rational values of the selected optimization criterion – the adhesion strength of the composite coating to the base during resistance welding of composite wires.

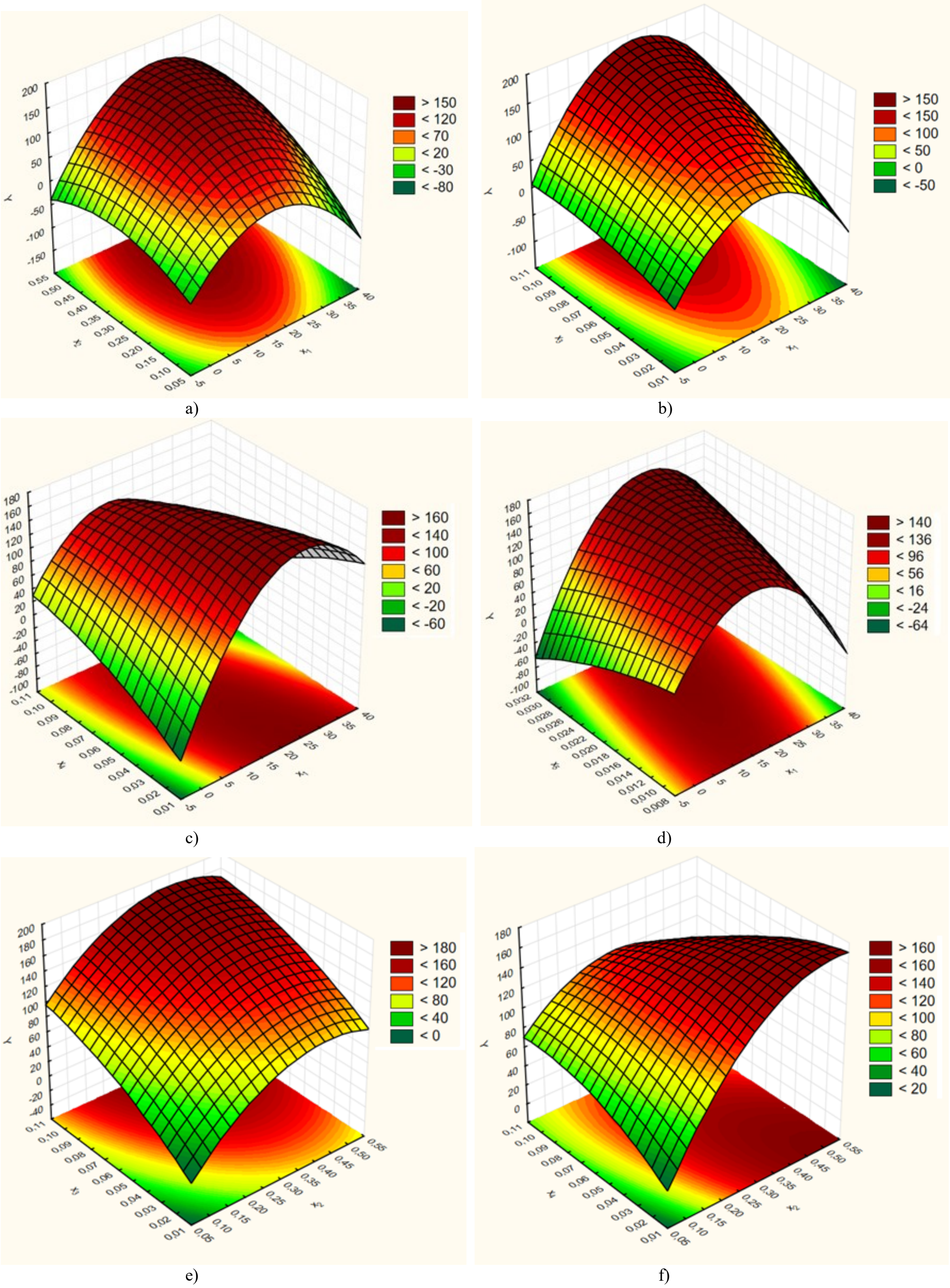


Fig. 4. Response surfaces and graphs of equal yield lines Y: a – $Y(x_1, x_2)$, b – $Y(x_1, x_3)$, c – $Y(x_1, x_4)$, d – $Y(x_1, x_5)$, e – $Y(x_2, x_3)$, f – $Y(x_2, x_4)$

Analysis of the response surfaces and graphs of equal yield lines for the selected optimization criterion (Fig. 4), as well as scatter graphs of the technological factors influence (Fig. 5), allows to determine their rational values: x_1 = 15.179 kA; x_2 = 0.3 MPa; x_3 = 0.06 s; x_4 = 0.06 s; x_5 = 0.01964 m/s. Taking into account the technological capabilities of the installation for resistance welding of composite wires when machining shafts ∅ 50 mm, the following values should be considered rational modes: welding current I = 15 kA; electrode pressure P = 0.3 MPa; current pulse duration τ = 0.06 s; pause duration τ_1 = 0.06 s; linear speed of part rotation V = 7.5 rpm.

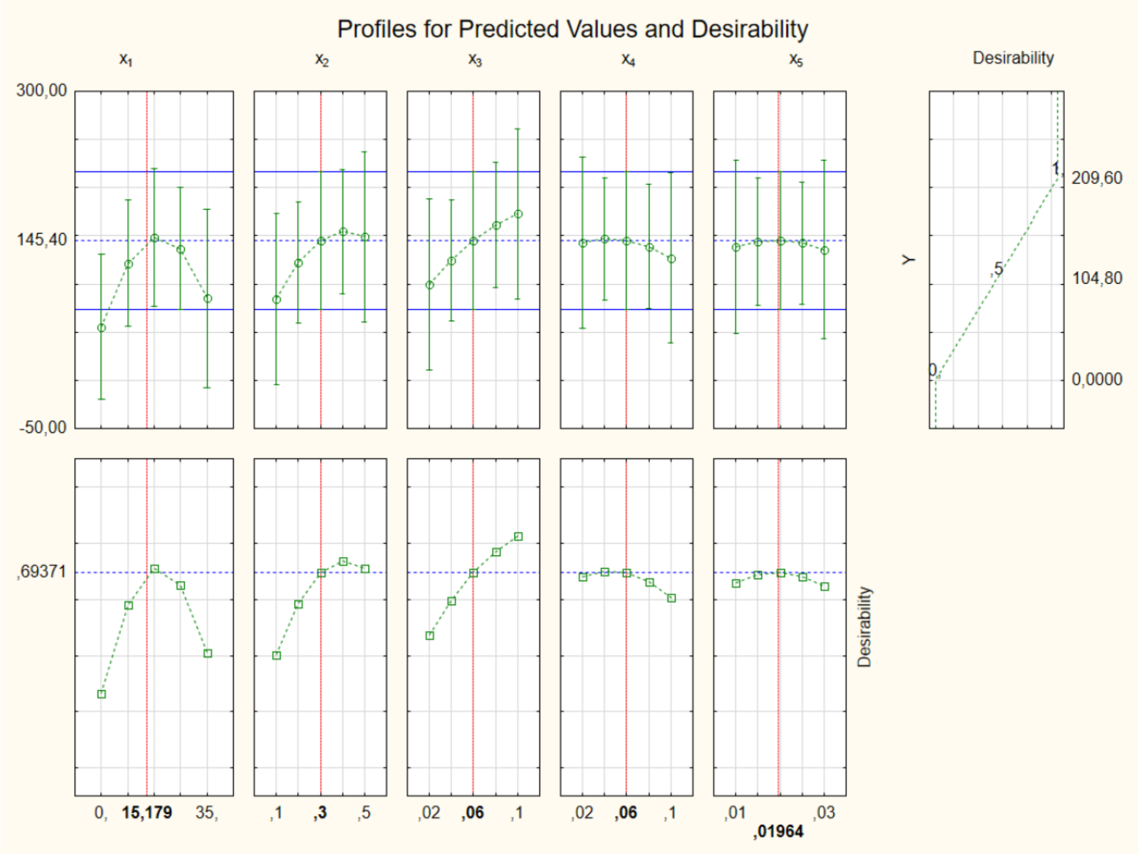


Fig. 5. Scatter graphs with histograms characterizing the influence of the studied factors on the adhesion strength of the composite coating to the base during resistance welding of composite wires

Conclusions

1. Given that the service life of agricultural machine shafts is significantly shorter than the service life of the machine as a whole, the issue of increasing the parts durability is particularly important.

2. The use of resistance welding technology of composite wires opens up great opportunities to improve durability.

3. Since the adhesion strength to the base is one of the main operational properties of parts that determine their durability, this parameter must be improved by selecting rational values for the resistance welding modes of composite wires.

4. To determine the optimal modes of applying composite coatings by resistance welding, an active experiment was performed using mathematical planning methods. The analysis of response surfaces and graphs of equal yield lines for the selected optimization criterion made it possible to establish rational values of the resistance welding modes. Taking into account the technological capabilities of the installation for resistance welding of composite wires, it is recommended to process shafts ∅ 50 mm at the following values: welding current I = 15 kA; electrode pressure P = 0.3 MPa; current pulse duration τ = 0.06 s; pause duration τ_1 = 0.06 s; linear speed of part rotation V = 7.5 rpm.

References

1. Kalinin E. (2020). Influence of the elasticity of shafts of agricultural machines with active working bodies on the forces in gear couplings. Technical and technological aspects of development and testing of new equipment and technologies for agriculture of Ukraine. 26. P. 74-82. [Ukrainian]

2. Stetsko A.E. (2013). Technological support of the service life of manufactured and refurbished parts. Lviv, ARS Publishing Company, 240 p. [Ukrainian]

3. Vasylenko I.F. (2014). Investigation of the properties of composite coatings applied by contact welding of cored wires. Collection of scientific papers of Kirovograd National Technical University «Technique in agricultural production, branch engineering, automation». 27. P. 60-67. [Ukrainian]

4. Luzan S.O., Kalinin E.I., Luzan A.S. (2021). Development of technology for the restoration of typical parts by surfacing composite materials. Technical service of agro-industrial, forestry and transport complexes. 23. P. 161-167. [Ukrainian]

5. Berezhnaya E.V. (2011). Restoration of machine tool parts by electrocontact surfacing with flux-cored wire. Tool reliability and optimisation of technological systems. 29. P. 175-179. [Ukrainian]

6. Aulin V.V., Vasylenko I.F., Krasota M.V. (2020). Theoretical substantiation of the operational properties of automotive parts hardened by composite coatings using the method of cluster components. Central Ukrainian Scientific Bulletin.. 3(34). P. 54-65. [Ukrainian]

7. Vasylenko I.F. (2015). Selection of flux-cored wire materials for application of composite coatings. Collection of scientific papers of Kirovograd National Technical University «Technique in agricultural production, branch engineering, automation». 28. P. 154-159. [Ukrainian]

8. Vasylenko I.F., Shepelenko I.V., Krasota M.V. (2010). Design of composite coating composition under abrasive wear conditions. Collection of scientific papers of Kirovograd National Technical University «Technique in agricultural production, branch engineering, automation». 23. P. 173-177. [Ukrainian]

9. Solovykh E.K. Methodological grounds for increase in the bearing capacity of functional coatings by constructive and technological methods [dys. ... d-ra tekhn. nauk: 05.03.07]. 2013. 516 p. [Ukrainian]

10. Solovykh E., Shepelenko I., Chernovol M. et al. Multicriteria optimization of heat-resistant coatings detonation spraying technology. Problems of Tribology. 2023. 28(4/110). P. 36–43. https://doi.org/10.31891/2079-1372-2023-110-4-36-4. [English]

11. Veselivska H.H., Student M.M., Posuvailo V.M. et al. Electrochemical Properties of PlasmaElectrolytically Oxidized Aluminum Coatings Sprayed on MA5 Magnesium Alloy. Mater Sci. 2023. Vol. 59. P. 49–55 https://doi.org/10.1007/s11003-023-00742-x .[English]

12. Tian N., Zhou S., Zhang C. et al. Effect of High-Current Pulsed Electron Beam Irradiation on the Microstructure and Mechanical Properties of Multilayered TiN/TiCN/Al2O3 Coatings. J. of Materi Eng and Perform 2023. https://doi.org/10.1007/s11665-023-08723-6. [English]

13. Solovykh E., Shepelenko I., Solovuch A., Katerynych S. Features of ion nitriding technology multicriteria optimization. Problems of Tribology. 2022. Vol. 27, № (4/106). P. 13–18. https://doi.org/10.31891/2079-1372-2022-106-4-13-18. [English]

14. Shepelenko I.V., Chernovol M.I., Leshchenko S.M., Krasota M.V., Nemyrovsky Y.B., Shumlyakovsky V.P. (2023). Search for optimal parameters of finishing antifriction non-abrasive treatment of cylinder liners of automotive tractor engines. Collection of scientific papers. Scientific Bulletin. Technical sciences. 8 (39)_II. P. 11–23. https://doi.org/10.32515/2664-262X.2023.8(39).2.11-23. [Ukrainian]

15. Shepelenko I. The study of surface roughness in the process of finishing anti-friction non-abrasive treatment. Problems of Tribology. 2020. 25(1/95), 34–40. https://doi.org/10.31891/2079-1372-2020-95-1-34-40. [English]

16. Vasylenko I.F. Increasing the durability of sowing machine shafts with composite coatings [Abstracts dys. ... kand. tekhn. nauk: 05.05.11]. 2001. 16 p. [Ukrainian]

17. Nalyvaiko V.M., Krylov O.V., Shepelenko I.V., Russkikh V.V. (1999). Methodology for assessing the adhesion of metal coatings used in the restoration of agricultural machinery parts. Proceedings of the Tauride State Agrotechnical Academy. 2(18). P. 56-62. [Ukrainian]

18. Vasylkovska K.V., Leshchenko S.M., Vasylkovskyi O.M., Petrenko D.I. Improvement of equipment for basic tillage and sowing as initial stage of harvest forecasting. INMATEH – Agricultural Engineering. 2016. Vol. 50 Issue 3. P. 13–20. [English]

Черновол М.І., Шепеленко І.В., Василенко І.Ф., Лещенко С.М., Красота М.В., Артюхов А.М.
Встановлення оптимальних параметрів контактного наварювання валів сільськогосподарських машин

В роботі виконано пошук оптимальних значень параметрів контактного наварювання композиційних дротів задля підвищення довговічності валів сільськогосподарських машин. За параметр оптимізації обрано міцність зчеплення композиційного покриття з основою деталі. Оцінку зчеплення композиційного покриття з матеріалом основи здійснювали методом нормального відриву. Для визначення оптимальних режимів нанесення композиційних покриттів проводився активний експеримент з використанням методів математичного планування. Отримані поверхні відгуку та графіки ліній рівного виходу дозволили встановити рівень впливу досліджуваних факторів на параметр оптимізації. Для аналізу впливу факторів на критерій оптимізації побудовані графіки розсіювання з гістограмами, які дозволяють графічно визначити раціональні значення обраного критерію оптимізації – міцності зчеплення композиційного покриття з основою при контактному наварюванні композиційних дротів. Реалізація центрального композиційного плану 2^{5-2} дозволила встановити вплив параметрів контактного наварювання композиційних дротів (сили зварювального струму; тиску на електродах; тривалості імпульсу струму та паузи; лінійної швидкості обертання деталі) на міцність зчеплення композиційних покрить з основою та визначити їх раціональні значення.

Ключові слова: контактне наварювання, композиційне покриття, міцність зчеплення, вали сільськогосподарських машин, оптимальні параметри