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RESEARCH

Perspective Method of Restoration of Autotractor Parts by Electrocontact Welding of Powder Materials in the Magnetic Field

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ABSTRACT

The cause of the failures of autotractor machines is mainly the process of inevitable wear of the mating parts. Moreover, it was proved that more than 80 % of parts of assemblies and assemblies of many tractors and cars fail with a slight wear of parts, sometimes not exceeding 0.1 mm. One of the progressive ways of restoration with obvious advantages compared with other similar methods of repairing parts is electrocontact welding of filler materials. One of the ways to expand the capabilities of technology is the application of metallic powder materials and their mixtures on the worn surfaces of automotive components in the magnetic field. Conducted research and obtained a number of results to determine the effectiveness of using the technology of contact welding of powder materials in a magnetic field. The optimal geometrical parameters of the electromagnetic device (d/2L=2,8) are determined with the smallest value of the magnetomotive force (F=1,25·10-3 A). The influence of the current of the excitation winding of the electromagnet on the thickness of the formed coating up to 1.5 mm or more is proved. The possibility of applying (welding) steel and cast iron chips with particle sizes from 400 to 1000 microns and controlling the thickness of the applied layer, changing the magnetic field and particle size of the chips was determined. In this case, it is possible to obtain a layer thickness of up to 1.6 mm. Tests on the wear of the samples showed high wear resistance of the welded coatings obtained in comparison with the reference steel samples.

1. INTRODUCTION

Restoration of parts is an important part of the repair of machines. At the same time, the restoration of parts can significantly reduce the consumption of new spare parts and provides significant savings in money and social labor, contributes to environmental protection by eliminating the steps associated with overproduction of parts [1-3]. When comparing the technology of overproduction of worn parts with the technology of its restoration, it becomes clear that overproduction is a long and expensive process, because during smelting and subsequent machining, irretrievable metal loss from corrosion, burnout, waste into chips reaches 40 % (with full production cycle parts). A cheaper and less durable is the optimal technology to restore worn parts.

The problems of restoration of machine parts by means of their restoration are being carried out all over the world, but the enormous scientific potential in field has been accumulated mainly in scientific educational organizations in Russia. Currently, there are various methods and ways of restoration developed by applying a layer on the worn surfaces of autotractor parts.

In their studies Voinash S.A., Gaidukov P.A., Markov A.N. [4] presented a modern approach to choosing the optimal route for restoring and repairing machine parts with full consideration of their operating parameters, as well as the economic rationale for using one or another repair technology. At the same time, the optimal recovery route is based on an analysis of dependency, which must satisfy the condition underlying the prevention system.

Strebkov S., Turyansky A., Bondarev A., Slobodyuk A. [5] proved the economic feasibility of restoring parts by replacing imported equipment by restoring, which sets certain directions for service organizations on the task of ensuring the working condition of foreign equipment in Russia. The analysis of the cost of repairing the parts using the example of the John Deer 7830 box cover taking into account the post-repair resource, shows on average a double reassessment of the cost of spare parts in the general structure of restoration costs.

Zhang H., Zhang H., Liu, Z., Miao [3], analyzed the characteristics and problems of assessing the operational reliability of large equipment, and also summarized the methods and improvements in study. In general, operational reliability assessment methods fall into two categories, which are model-based and map-based.

Curtis Richard, in work [6], describes research on modern repair technologies that go beyond repairing cracks and bring the repair of a machine as close as possible to its original state, by restoring the airfoil profile, redesigning components and increasing equipment service intervals.

In the article [7], present the results of the study of the physicomechanical properties of oxide-ceramic coatings formed by plasma electrolytic oxidation on various aluminum alloys. It was found that filling the pores of an oxide-ceramic coating with oil or applying a layer of copper on its surface by a friction-mechanical method increases the wear resistance of moving joints of machine parts by 1.7 and 4.5 times, respectively.

In works Nafikov M.Z. [8,9] describes technological methods for restoring various parts, mainly shafts, by electrocontact welding of metal wires on the wear surface. Theoretically and experimentally, the wire welding conditions were selected and factors affecting the quality of the reconditioned coatings were determined.

When considering the use and regulation of the magnetic field in the restoration of parts by electrocontact welding of metal powders, the results of studies were taken into account in the works of the authors Schetinin V.I., Schetinin S.V., Gaytov B.K., Kashin Yu.M. [10,11], where they experimentally proved the influence of the size of the magnetic circuit (electrode) on the magnetic field induction and electromagnetic force, as well as obtaining a magnetic closed circuit of axial welded equipment.

Slade P.G., Taylor E.D., and Lawll A. [12] studied the mechanism of operation of closed vacuum interrupters in the transmission of short-circuit currents, especially during short-term contact. According to the research results, the authors propose calculations for the total contact closing force and compare the difference in the calculations of the force in the threshold welding current between the three contact structures. study is interesting from the point of view of approaches to determining the forces of magnetism when electric current passes through copper contacts, which in itself is analogous to the process of electrical contact welding.

It is obvious that in the repair of any equipment it is economically and technologically expedient to use the restoration of expensive worn parts, since the manufacture of new parts is quite expensive. At the same time, from the numerous micro-measurement data given in the literature for various reconstructed parts, it follows that the absolute values of wear are insignificant both in linear dimensions and in weight loss.

An extensive analysis of the geometry (length, width, height, diameter and dimensions of working surfaces) showed that in the repair industry, when restoring parts from the total mass, there are covered cylindrical parts, respectively, with slight wear up to 0.6 mm of the outer surfaces, i.e. parts of shaft type, with a range of part diameters from 10 to 80 mm and a length of up to 800 mm. Therefore, in our opinion, the choice of the most appropriate restoration technology should be based on the results of the readings of the fault detection of parts and technological possibilities of obtaining high-quality applied coatings on the working surfaces of machines with the listed geometrical parameters and with the least loss of metal.

Long-term studies of scientists in the field of repair and restoration of parts show that the characteristic of the geometric shape of machine parts and wear is different, but most of the parts of tractors and cars wear unevenly and most of the shaft-type parts installed on tractors, cars and agricultural machines are important and costly. When restoring such parts, it is necessary to strive to take into account all the quality indicators on which the durability of the parts and the working life of the entire machine depend. However, on the basis of a priori information and screening studies, it has been proved that there are many factors that influence the quality of the reconditioned parts.

One of them is a private factor and from the point of view of the quality of restoration, they have the greatest influence on the process of formation of the coating. So when restoring a particular part in any way, determining theoretically or experimentally, it is possible to minimize the harmful and maximize the positive impact of these factors and thereby obtain the required quality of the restored surface.

To ensure the reliability of the reconditioned shaft-type parts, it is necessary to strive to improve all the quality indicators of the reconditioned parts restoring their life. Under certain conditions, it is possible to upgrade and improve one or another recovery method for a selected group of parts.

It is known that in order to restore small and medium-sized parts with a small amount of wear, electrocontact welding of powder materials and their mixtures is a universal method.

The most obvious advantages of this method are higher productivity of the process (60 cm^2/min), insignificant depth of the heat-affected zone, no deformation of the part during the process and after restoration of the parts, the possibility of combining the hardening of the surface of the applied layer with the welding process, minimal loss of metal powder (3...4 times compared with arc recovery methods), the ability to control the thickness of the applied layer and high environmental friendliness of the welding process.

1.1. Purpose Of The study

Theoretically and experimentally to investigate the influence of a magnetic field on the formation of a restored surface and the subsequent evaluation of the quality indicators of the coatings obtained during the electrocontact welding of powder materials and their mixtures to shaft-type parts.

2. MATERIALS AND METHODS

In order to conduct research to identify the influence of the magnetic field on the process of surface formation during the electrocontact welding of powder materials, the most technologically advanced designs of magnetic conductors were experimentally identified. As a result, for the theoretical justification the design of the magnetic core was chosen, the circuit for supplying the surface of the part and the path of the magnetic field through the part is shown in Fig. 1.

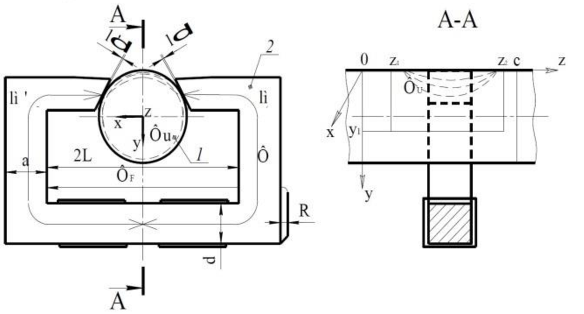


Fig. 1. Diagram of the supply of a magnet to the surface of the part: 1 – details; 2 - electromagnet [10-12].

As can be seen from the figure, to reduce the flux of scattering (Φ_F), it is sufficient to bring the ends of the magnetic core tightly to the surface of the restored section directly from the opposite sides theoretically assuming that under these conditions the magnetic field will sufficiently pass through the restored section of the part along a closed magnetic circuit with the least resistance (Fig. 1) [12].

In reality, the tight fit of the electromagnet poles will not be ensured due to the formation of gaps l_δ l_δ' between the poles and the cylindrical surface of the part, but when magnetized the magnetic circuit will be provided with symmetry, then taking it into account Kirchhoff's equation takes the form [10-12]:

$$\varPhi \cdot R_M + \varPhi_F R_F = F \tag{1}$$

$$\varPhi_U \cdot (R_\delta + R_U) - \varPhi_F R_F = 0 \tag{2}$$

$$\varPhi = \varPhi_F + \varPhi_U \tag{3}$$

Theoretically assuming that the magnetic flux from the poles of the electromagnetic device penetrates the part $\varPhi_U = B_\text{Э} \cdot S_\text{Э} = \mu\mu_0 H \cdot d \cdot R$ and, solving the equations presented above (1-3), determined the magnetic force of the electromagnet [12]:

$$F = \varPhi_U \left[\left(\frac{R_\delta + R_U}{R_F} + 1 \right) \cdot R_M + R_\delta + R_U \right] \tag{4}$$

Considering the accepted designations shown in Fig. 1, and the magnetic permeability of various materials of the parts being repaired, the magnetic resistance was determined [13-14]:

$$R_U = \frac{\int_0^{L+\frac{d}{2}} H(X,0,\frac{C+R}{2})dx}{\int_0^{y_1}\int_{Z_1}^{Z_2} \mu(H) \cdot H_1 dydz} \tag{5}$$

In this case, the magnetic flux is obtained in the numerator, and the denominator is the fall of the magnetic potential in the part, which depends on the magnetic permeability *μ(H)*, the field strength *H* and the diameter of the section of the part being restored.

Using the formulas obtained, it is possible to more accurately determine the design parameters of an electromagnetic device.

The main purpose of using the magnetic field in the welding zone is to increase and retain the ferromagnetic powder at the time of its welding to the surface of the part. Here it is necessary to create high magnetic flux intensity in the welding zone. A diagram of the formation of a powder layer on the surface of a part using a magnetic field is considered in Fig. 2 [12].

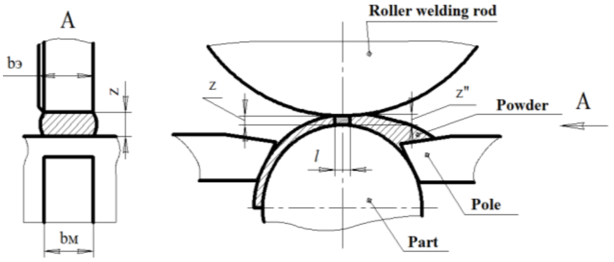


Fig. 2. Diagram of formation of the thickness of the applied layer.

One of the characteristics of electrocontact welding is the intermittency of the deposition process [8-9, 13-14]. Considering the process of welding the powder as a separately welded point, in form it most of all comes in the shape of an ellipse. Assuming that the welded point has a symmetrical shape with the same dimensions on the sides (l = b) and different layer density in different parts, then to simplify the study, the shape of the weld point is represented as a prism with sides l, b and z. Considering the above, the thickness (Z) of the welded layer will be determined by the following relationship [12]:

$$Z = \frac{V}{S} = \left(\frac{m/\rho}{S} \right) \times k \tag{6}$$

where ρ- is the density of the sintered coating, g/cm^3; m - is the mass of magnetized powder, kg; $S = l \times b$ -is the welding spot area, m^2; $k = (z - z^I)/z$ is the powder shrinkage.

Formula 6 is a mathematical reflection of the formation of the thickness of the applied layer presented in Fig. 2. In the resulting relationship for determining the mass of the powder *m*, Fig. 3 shows a diagram of the acting forces on the ferromagnetic powder located on the restored surface of the part in the time interval when there is no welding current pulse.

The diagram shows that the main operating force that attracts the ferromagnetic powder to the surface of the part is the force determined by the magnetomobile force $F_{МДС}$ created by sequentially passing the magnetic flux through the designated system "magnetic circuit – part" [10-12].

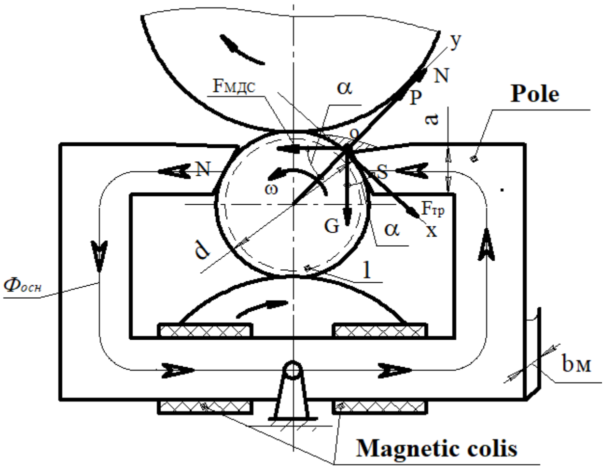


Fig. 3. Diagram of the forces acting on the ferromagnetic powder.

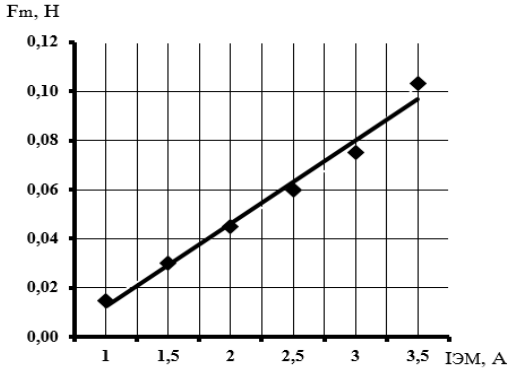


Fig. 4. Graph of the dependence of the force F_m on the current of the excitation winding of the electromagnet $I_{ЭМ}$.

The unit of measurement of the magnetomotive force $F_{МДС}$ is Ampere, but the forces represented in the diagram are measured in Newtons.

To find the force determined by the influence of $F_{МДС}$, a translation experiment was conducted, the main result of which is presented in Figure 4 as the dependence $F_m=f(I_{ЭМ})$. The resulting graph allowed us in subsequent calculations to translate the force (F_m), determined by the influence of the magnetomotive force $F_{МДС}$, on the current of the ЭМ ($I_{ЭМ}$) excitation winding. Using the obtained formulas and graphs, the formula for determining the mass (m) of the ferromagnetic powder in the welding zone and the thickness of the resulting coating (Z) were obtained [12]:

$$m = \frac{F_m \cdot (\sin\alpha - f \cdot cos\alpha)}{(\cos\alpha - f\sin\alpha) + f \cdot \omega^2 \cdot R} \qquad (7)$$

$$Z = \frac{k \cdot F_m \cdot (\sin\alpha - f \cdot cos\alpha)}{S \cdot \rho \cdot ((\cos\alpha - f\sin\alpha) + f \cdot \omega^2 \cdot R)} \qquad (8)$$

Experimental studies were carried out by a well-known method [4, 8-9, 13-14]. The application of the ferromagnetic powder on the worn surfaces of the parts was carried out on a serial installation for electrocontact welding of filler materials. To implement the experiments, the experimental setup was additionally equipped with a metering device with an electromagnetic coil and a power source, which facilitated the metered supply of ferromagnetic powder at the time of welding. In the manufacture of the magnetic circuit, all technical and electrical parameters of the material were taken into account, as well as the magnetic circuit and its structural elements to enable the application of powder to parts of different diameters. The regulated electric current to the magnetic circuit comes from a specially designed current source.

Cylindrical samples (with the diameter from 20 to 80 mm) from the material reasonably selected from steel of grades 35.45 [15, 16] were used as experimental samples. Ferromagnetic industrial powders according to State Standard 9849 - 74 of the PZh – 2, FBH – 6–2 grades, steel (steel 45) and pig-iron (SCh 18) chips with particle sizes of 400–1200 microns were chosen as the filler material.

To measure the readings by the magnitude of the welding current and the current of the excitation winding of the electromagnet, standard measuring devices were used. In this case, the mode of welding or deposition of ferrimagnetic powder materials was established on the basis of scientifically grounded recommendations and conclusions of researchers in this field [6, 17, 18].

Evaluation of the degree of influence of the magnetic field on the loss of ferromagnetic powder, the effect on the thickness of the applied layer was determined by comparing the readings of the power source ammeter and the mass of the remaining powder materials on the surface of the part at the welding point.

Evaluation of the quality indicators of the coatings obtained (adhesion strength, hardness, porosity, wear resistance, etc.) were determined according to a known method using specialized test equipment.

3. RESULTS AND DISCUSSION

Experiments on the application of ferromagnetic powder on the surface of the part showed good results on the density and uniformity of the layer obtained, insignificant losses of the ferromagnetic powder, and the preparation of multilayer coatings.

The design of the installation allows the welding of ferromagnetic powders according to different application schemes.

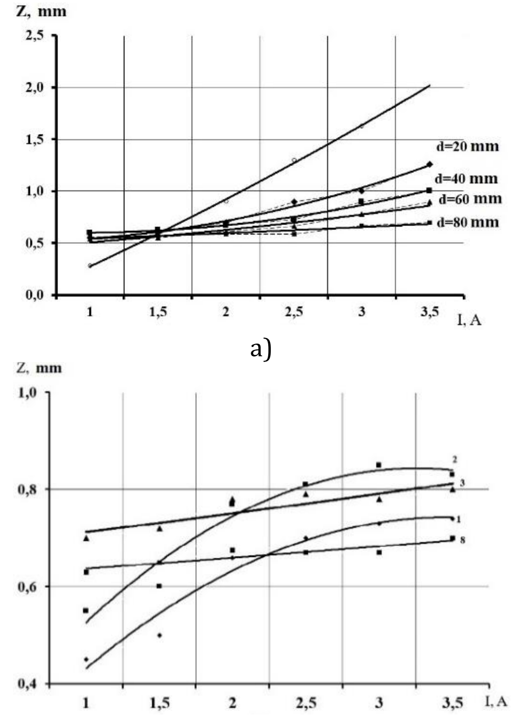


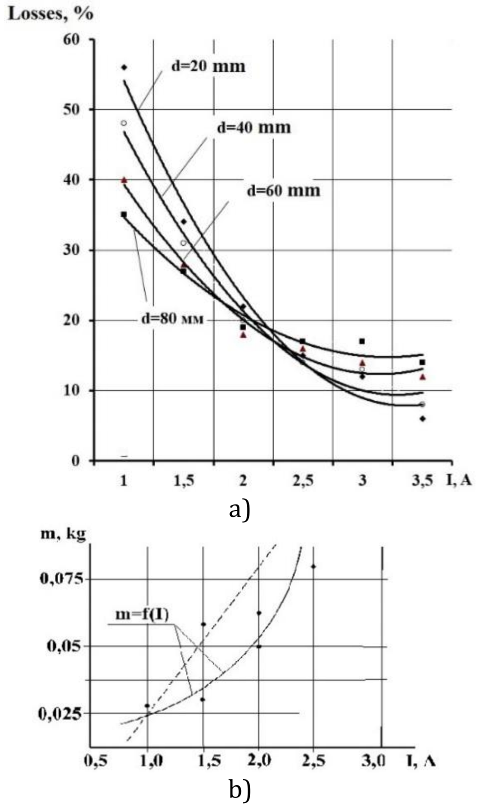
Fig. 5. Graphs: a) dependence of the current of the electromagnet ($I_{эм}$) on the thickness of the applied coatings (Z), with different diameters of parts; b) dependence of the thickness of the resulting coatings (Z) on the current of the electromagnet ($I_{эм}$) and the particle size of the ferromagnetic powder in microns: 1 – SCh 18 (200 - 400); 2-SCh 18 (400 - 1000); 3 – Steel 45 (200–400); 4 – Steel 45 (400–1200).

As a result of processing the experimental data, it can be seen that the pulse of the welding current affects the accumulation of the ferromagnetic powder and thus the change in the thickness of the applied coating. Strengthening the magnitude of the electromagnetic current affects the formation of the thickness of the applied coating where, due to its effect, the layer thickness reaches 1.6 mm. With various welding schemes it is possible to regulate and obtain various coating thicknesses.

In addition, experimental studies have shown that the thickness of the resulting coatings also changes when applying powders with different sizes of fractions of a ferromagnetic powder and the magnitude of the electromagnetic current ($I_{ЭМ}$) (Fig. 5). For example, when applying ferromagnetic powders in an alternating magnetic field and using pig-iron and steel chips, it allows a complex increase in the thickness of coatings. At the same time, the bulk density of pig iron chips is much smaller than the bulk density of steel chips, so when using pigiron chips, the layer thickness is formed much more intensively than when steel chips are applied [19]. When implementing the experiments, chips with a particle size of 800...1000 microns were used. The greatest effect on the formation of an adjustable layer of coating thickness is achieved by increasing the electromagnetic current and reaches up to 0.4 mm, compared with a simple backfilling of the powder in the welding zone. Using the chips with particle sizes less than 400 microns, the thickness of the applied coating remains practically unchanged. Conditions for the formation of the best quality coating is the optimum welding mode. In the course of research, the main modes were determined on a practical basis: the welding current (I_{wld}) was 7–8 kA, and the average longitudinal supply (S_{lnt}) was 3.35 mm/rev, and the application technology was accompanied by abundant water supply.

One of the important indicators of the welding (deposition) of a ferromagnetic powder on the surface of the parts to be restored by electrocontact welding is the loss of the filler material. In the course of practical experiments to estimate this indicator using an electromagnet, the location of the magnetic circuit relative to the disk electrodes was found to significantly affect the shedding of excessive ferromagnetic powder. The best effect of magnetization of the restored section of the part is achieved when installing the magnetic circuit of the electromagnet in the same axis with the welding electrodes. The graphical results of the experiments are presented in Fig. 6a.

The Fig. 6a shows that with the smallest current of the electromagnet ($I_{ЭМ}$=1A) for samples with a small diameter up to 20 mm, the loss of the filler material - powder is about 60%, with increasing diameter of the samples, the losses are reduced when using samples of 80 mm losses will be no more than 40 %. In turn, the magnitude of the current of the electromagnet (Iэм) to 3.5 A reduces the loss to 10 %.



a)

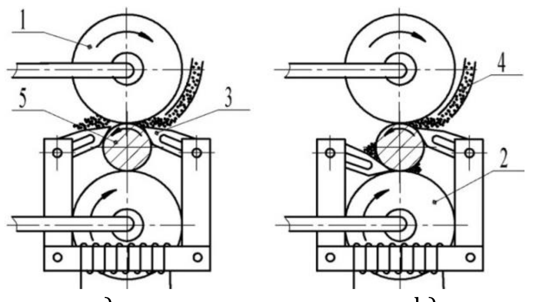
b)

Fig. 6. The results of experimental studies: a) effect of the magnitude of the loss of ferromagnetic powder; b) dependence of the mass (m) of the powder held in the welding zone on the current of the electromagnet (Iэм) and the diameter of the samples.

Technological properties of powders are also important, which also affects the formation of the coating thickness. The results of research in this direction consisted in comparing theoretical premises with experimental ones and for determining the mass of the ferromagnetic powder in the welding zone, which later determines the thickness of the applied coating. Correlation analysis of the previously described theoretical hypothesis and experimental data was carried out by measuring the mass of the ferromagnetic powder on the surface of the part at the time of its welding, in various welding modes with a change in the magnet current of the electromagnet on samples of 50 mm in diameter. The research results are presented in the figure (Fig. 6b). The resulting graph shows that with an increase in the concentration of ferromagnetic powder at the time of welding, it coincides with the moment of passage of the current pulse passing through the electro-component-electrode system, as well as the effects of an external magnetic field with an increase in the electromagnet current to 2.5 A. The subsequent increase in the magnet current does not affect the concentration of the greatest amount of ferromagnetic powder. As can be seen from the graphical results, there is a slight discrepancy between the curves obtained experimentally and theoretically.

The conclusions of studies of one of the most important indicators of welding powders, prove that the use of an external magnetic field at the time of applying (welding) the powder has the ability to reduce losses during the restoration of cylindrical parts.

The study of quality characteristics is the final analysis of the use of the developed method in practice. One of the main characteristics of quality is the strength of adhesion of applied (welded) ferromagnetic powder with the base metal. The definition of this indicator was carried out according to the standard method The studies used various application schemes and ferromagnetic powders and iron shavings of different sizes and grades. To compare the adhesion strength, a single piece of steel 45 was used. Experiments showed that the adhesion strength of the obtained coatings using metal chips with particle sizes of 800-1000 microns decreases by about 30 MPa. In the course of experiments, it was found that it is possible to produce welding of powders by the developed method using two flow charts: the first is to feed the powder into the upper welding zone; the second is to feed the powder simultaneously in the upper and lower welding zones (Fig. 7).



a) b)

Fig. 7. Diagrams of ways to install the electromagnetic poles and powder supply to the welding zones: a) first diagram is the feed to the upper welding zone; b) second welding diagram is the feed to the upper and lower welding zones: 1,2 - electrodes; 3 - ЭМ pole; 4 - powder core; 5 - recoverable part.

It was established that the method of feeding powder materials also affects the adhesion strength of coating to base. When applying the second application schemes of welding, the adhesion strength of obtained coating decreases by about 30 MPa and especially when using an filler material with particle sizes of 800-1000 microns.

Therefore, in order to achieve reference strength, in some cases, it was necessary to increase the welding current to 700 A/mm, and the pressure on the rollers to 300 N/mm. Low adhesion strength (from 110 to 120 MPa) was observed in samples obtained using pig iron chips. This filler material is suitable for parts experiencing light loads. The use of steel shavings and ferromagnetic powder grade FBH – 6–2 shows good strength results up to 180 MPa. During the experiments it was revealed that in order to obtain high adhesion strength, it is necessary to regulate the modes of application (welding). During long-term tests and experiments, the most optimal deposition regimes for the recommended powders were determined.

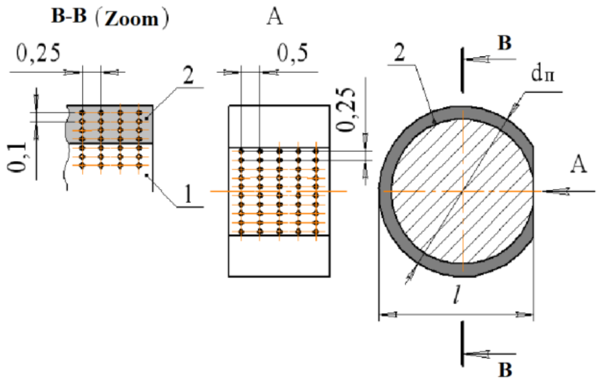


Fig. 8. Microhardness measurement diagrams: 1 - base metal; 2 - welded surface.

To analyze the quality of the coatings obtained, according to the known method, metallographic studies were carried out. The results of studies of samples obtained using various filler powders described above and in different modes, showed that in most cases the junction zone indicates a qualitative diffusion of the powder into the main one. To study this indicator, microhardness was also measured over the depth of the joint zone, which showed that the microhardness in the resulting surface using steel chips has rather high values - 6100 ... 6300 N/mm². An important step in evaluation of the hardness of obtained coatings was measurement of the microhardness distribution over depth of sample. The measurement was made by pressing the diamond tip. To implement the experiment, «PMT-3» microhardness tester was used. The load on the diamond pyramid during measurements was 0.981 N. For convenience, all the obtained data on values of hardness and microhardness were translated into hardness values on the HRC scale whenever possible (Fig. 8).

The results of microhardness measurements are presented in Fig. 9.

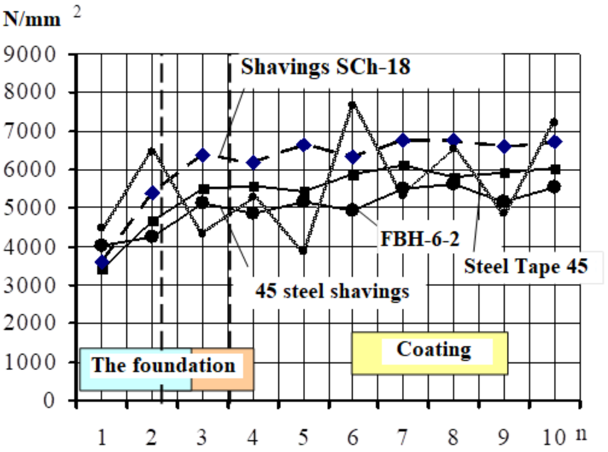
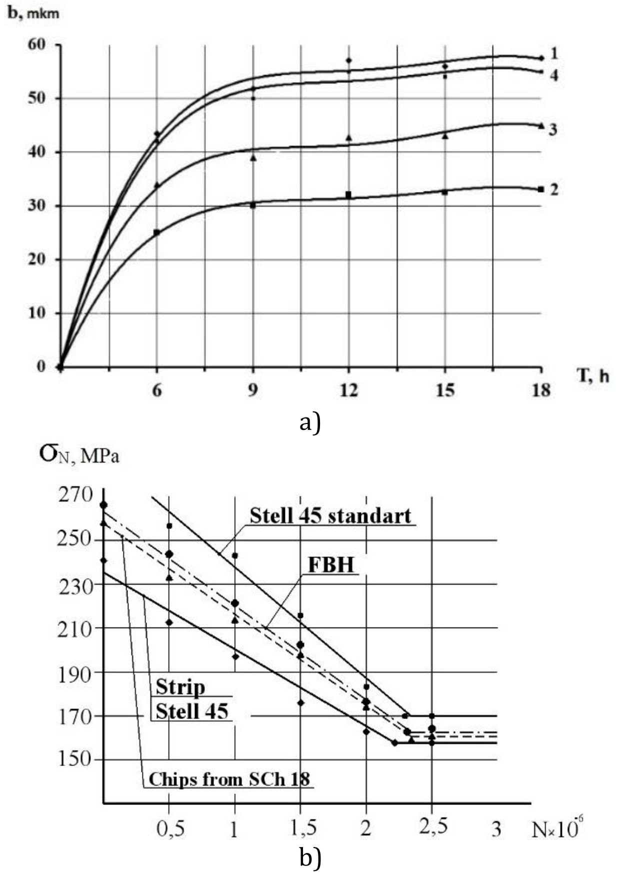


Fig. 9. Microhardness measurement results by sample depth.

It can be seen on the Fig. 9 that the results of microhardness measurement over the depth of the joint zone showed that the microhardness in the powder layer made of steel chips has values of 6100 ... 6300 N/mm² and of pig-iron chips of 6350 ... 6450 N/mm². At the same time, the dispersion of microhardness values over the entire layer is small. This is due to the fact that the magnetic field of the electromagnet contributes to concentration of the filler material in the welding zone providing a layer of powder under the electrode at the moment when welding current passes. The heat-affected zone is 0.5 ... 0.7 mm to the depth of base. In this part, due to the phenomenon of tempering, the hardness is less than about two times. The obtained values of hardness and microhardness indicates the possibility of obtaining homogeneous, uniform powder and wear-resistant reconditioned coating.

The microhardness of the surface layer of the samples obtained with the use of pig iron chips showed values higher - 6350 ... 6450 N/mm² [7].



a)

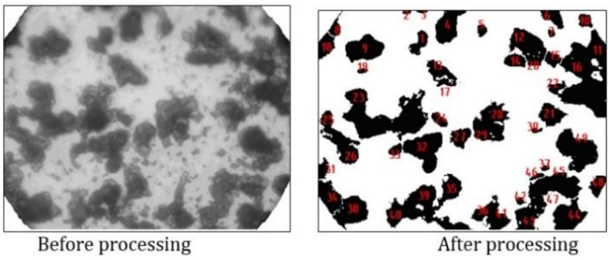
b)

Fig. 10. Test results: a) for sample wear: 1 - uncoated (standard); 2 - coated with SCh 18 chips (400 - 800 microns); 3 - with powder coating FBH – 6–2; 4 - coated with steel chips (300-1000 microns); b) fatigue strength.

Also one of the indicators of the quality of the coatings produced by electro-contact welding of powder materials is the porosity of the coatings. This indicator was evaluated on the coatings of the samples obtained, in various modes of welding, with the simultaneous condition of sufficiently high adhesion of the coating to the base. At the same time, when the current control range of the electromagnet was changed from 1 to 2.5 A, the porosity changed slightly (from 5 to 10 %). The porosity of the welded surface serves as a qualitative and quantitative characteristic of powder materials and determines the density and other physical and mechanical properties of the parts.

The porosity of the layer depends on the pressure of the electrode roller on the heated powder. In the experiments carried out, the pressure remained at constant level; the parameters of current magnitude and deposition rate also were set stable. The variable parameters are current magnitude of the excitation winding (magnetic induction), the diameter of the samples, material and granulation of reasonably selected powders. Experiments were carried out to determine the porosity and nature of pores distribution in zones of junction of powder and base metal as well as throughout the thickness of the welded layer.

The open porosity was determined by method consisting in measuring the lengths of microstructure segments containing porous inclusions. Summing up the lengths taking the porous part of surface and dividing the resulting number by the total sum of the lengths the percentage of porosity was obtained.



Before processing

After processing

Fig. 11. Microstructures photos processing.

Open porosity was determined by processing photographs of microstructures on a computer using an appropriate program (Fig. 11). A further increase in the intensity of the magnetic field made it possible to obtain a non-porous coating [9-12].

Conducted wear tests showed a low degree of wear of samples of welded coatings with test powders, steel and pig iron chips in comparison with reference steel samples. Thus, for example, during testing, the smallest wear of the surfaces of samples obtained by welding pig iron chips, the surface of which was porous and had anti-friction properties, was recorded [7]. Comparative tests on the cyclic strength of samples obtained by welding ferromagnetic powders revealed higher strength compared to samples obtained by welding steel strip (Fig. 10b) [5].

4. CONCLUSIONS

During the experiments, it was found that the external influence of the magnetic field allows to improve the manufacturability of the electrocontact welding process due to the concentration of ferromagnetic powder materials in the welding zone and reduces the loss of expensive powder material. In theoretical studies, the optimal geometrical parameters of the electromagnetic device ($d/2L=2,8$)) were determined with the smallest magnitude of the magnetomotive force ($F=1,25\times10^{-3}$ A). It is also proved that increase in the current of the excitation winding of the electromagnet to 3.5 A contributes to increase in the thickness of the resulting coating to 1.5 mm or more. The possibility of applying (welding) steel and pig iron chips with particle sizes from 400 to 1000 microns on the surface of the samples was successfully tested. Research results also showed the possibility to control the thickness of the applied layer (up to 1.6 mm) by changing the particle size and the influence of the magnetic field. Good results have been obtained on the technological and operational properties of surfaces [7,19].

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