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Effect of Gauze Filler Material on the Coating Properties for Electro-contact Welding

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Abstract

The paper presents methods and results of the study of the coating resulting from gauze welding, and the effect of this coating on the adhesive strength depending on electro-contact welding modes, material and gauze parameters, residual stresses in coatings, and coating wear resistance. According to the results of the analysis of calculations and experimental measurements, it was found that the thickness of the built-up layer of the metal coating depends on the grid parameters and can be calculated using the derived formulas. During electro-contact welding in modes: $I = 2.0\text{-}2.1$ kA, $t_{imp} = 0.06$ s., $t_{pause} = 0.08$ s., the adhesive strength of the woven gauze (174 MPa) is 41% higher than the steel tape (102 MPa). It was found that the wear rate of the woven gauze coating (45 steel) layer is 15% lower than the wear rate of the without coating (45 steel) sample. It is shown that coatings made of tape and powders have twice as many residual stresses as coatings made of gauze. The study results were used to develop the technology for the restoration of automotive parts, which helps effectively restore parts and save on the cost of purchasing new ones.

Keywords: Adhesive Strength; Electro-contact welding; Gauze filler material; Residual stresses; Restoration of parts.
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1. Introduction

Electro-contact welding is a type of fusion welding with short-term heating of the junction of metals. A characteristic feature of these processes is the convergence of the welded metals to the interatomic distances through plastic deformation of the connected surfaces.[1] Depending on the type of filler material, there are also methods of electric contact welding. Although steel wire was used as the first filler material for electro-contact welding, the diameter and grade of which were determined by the required thickness and coating properties, the most used materials for restoring worn surfaces of parts of the "shaft" type are steel tape and powders.[2] The disadvantages of electro-contact welding of wire make it difficult to conduct helical surface welding and obtain a high-quality welded joint between the wire loops.[3]

Today steel tape is used as a filler material for electro-contact welding more often because it has advantages such as the quenching possibility during welding, high reliability, and manufacturability. When using electro-contact welding of steel tapes, joining base and filler materials is accompanied by the formation of weld metal.[4–6] There are different steel tape welding methods through an intermediate layer of amorphous solder,[7] using powder material and amorphous strip solder[8] as a sub-layer, which improves the properties of the built-up layer. At the same time, the impact of hardness and fatigue life is reduced to 10%. Despite these advantages, a more detailed analysis showed that the use of steel tape reduces the technological process productivity since the tape preparation (marking, cutting, Stripping) takes more time than the welding process itself.

Powder materials are considered to be more promising filler materials for electro-contact welding. The use of powder mixtures (compositions) allows for obtaining a wide range of different properties: corrosion resistance, wear resistance, friction, anti-friction, heat resistance, erosion resistance, *etc*.[9] In addition to the mentioned advantages of using powder materials, there are also disadvantages. Difficulty in ensuring the retention of powder in the welding zone is the main disadvantage. For more effective retention of powder-polymer tapes and reinforced sintered tapes are used as powder materials.[2] Thus, powder materials are not always appropriate, especially for the restoration of parts, which coatings do not require unique properties.

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In a comparative analysis of electro-contact welding methods of various filler materials used aimed at restoring the surfaces of worn parts, it was found that welding of steel tape has the highest producibility. A significant disadvantage of this material compared to a steel wire coating is a relatively low adhesive strength between the coating and the part's base metal.[1,4] Simultaneously, the main disadvantage of contact welding of steel wire is its low producibility, which requires precise positioning of the welding head and wire feed. Besides, the risk of wire breakage increases during welding.[10] Thus, to combine technological and qualitative indicators of electro-contact welding, it is advisable to use gauze filler materials, which possess all mentioned indicators.

Gauze in welding is effectively used as a base metal for single welding of flat butt joints in shipbuilding.[11] When selecting the optimal modes of electro-contact welding, there are methods for measuring the resistance and welding circuit impedance in contact machines.[12] Thus, for calculating the optimal welding modes, the temperature distribution during spot welding of steel cross rods was studied.[13] The processes are modeled over several consecutive time stages corresponding to changes in the contact area, the associated contact resistance, and a decrease in the released power. Work[14] studied the temperature distribution and thermal influence zone during spot welding of aluminum products. This allows for determining rational welding modes. A three-dimensional thermal and electromechanical model was obtained for contact spot welding of Usibor 1,500 hot-stamped boric steel. In order to identify the range of adequate parameters for contact welding, work[15] considered changes in dynamic contact resistance with changes in the welding process parameters, such as welding current, welding time, and electrode force. For the control and management of the optimal modes of contact spot welding, an algorithm of the contact spot welding process recorded with a high-speed camera has been developed.[16] A more advanced image processing technology for optimizing welding modes is described in the work.[17] The work proposes to create a real-time Denavit-Hartenberg model (D-H) and solve direct and inverse kinematic robotic arm models with six degrees of freedom (6DoF). The weld quality assessment can be processed within 0.5 s with very high accuracy. It is possible to predict the quality of the weld and control the technological parameters of the contact welding process using multiple regression analysis, which takes into account the influence of welding parameters on the amount of bending force and the amount of workpiece deflection.[18]

A more significant technological factor for the process of electro-contact welding, which determines the heating and degree of plastic deformation of the filler material, is the effective amount of the welding current. The Joule-Lenz law should be used in research to determine the welding current, taking into account heat balance during the formation of a single welding point. A mathematical model based on the application of Joule's and Fourier's laws was used in a like manner to study the heat-transfer processes of the contact system of a high-current circuit breaker.[19] Joule's law was also applied for diagnosing high-voltage equipment connector pins based on the temperature dependence on the current strength.[20]

The paper aims to identify the characteristics of the gauze filler material, which can ensure the continuity and wear resistance of the coating, and to determine electro-contact welding modes resulting in high adhesion.

2. Materials and Methods

2.1 Calculations

Stages of experimental research

The study of the adhesive strength of coatings to the base metal of the part depending on the material, metal gauze parameters, and electro-contact welding modes;

the study of residual stresses in the resulting coatings;

the study of wear resistance of coatings;

operation tests of parts restored by electro-contact welding of gauze filler materials.

In order to determine if gauze filler materials are suitable for electro-contact welding, it is necessary to calculate the gauze parameters, such as gauze wire diameter and the size of a gauze cell.

The planned thickness of the coating, m:

$$h = \frac{\gamma}{\rho(1-p)} \tag{1}$$

where γ – the mass of 1 m^2 of the gauze, kg/m^2; ρ – the density of the gauze material, kg/m^3; p – porosity (chosen depending on the required coating integrity, usually 0.01-0.10).

The planned thickness of the coating can be calculated by the parameters of the gauze

$$h = \frac{\pi^2 d^2 (R_y \delta_y + R_o \delta_o)}{360(a+d)^2(1-p)} \tag{2}$$

where d – wire diameter, m; a – cell size, m; R_y, R_o – radius of curvature of the weft and warp wires, respectively, m; δ_y,δ_o – the angle of bend of weft and warp wires, respectively.

Equations (1) and (2), and gauze parameters allow determining the planned coating thickness shown in Table 2.

Under Joule's law for the experimentally studied case of surfacing,[10] the total amount of heat generated between the specific filler material and a part of a certain diameter (Q_E) during surfacing is determined as:

$$Q_E = I_E^2 \cdot R_E \cdot t_{IE} \tag{3}$$

where I_E is an experimentally determined current strength for a specific filler material and a part of a certain diameter; R_E is the total resistance of the specific filler material and a part of a certain diameter, Ω; t_{IE} - welding current pulse duration, sec. If it is granted that $R = R_E$, then for any case of surfacing, the current strength is equal to

$$I = I_E \sqrt{Q/Q_E} \tag{4}$$

where I_E is an experimentally determined current strength for a specific filler material and a part of a certain diameter; Q is the amount of heat released in the welding zone, calculated for an arbitrary case, J; Q_E is the amount of heat released in the welding zone, calculated for a specific filler material and a part of a certain diameter, J.

The heat balance equation (5) for forming a single weld point can be written as:[10]

$$Q = Q_1 + Q_2 + Q_3 \tag{5}$$

where Q_1 is the amount of heat required to bring the portion of filler metal between the part and the roller electrode to a plastic state, J; Q_2 and Q_3 – the heat withdrawn during a t_{IE} single current pulse from the weld point to the part, roller, and filler wire, respectively, J.

By substituting equation values (3) and (5) into Equation (4), the current strength for any case can be determined. The elements of the heat balance equation are determined by the method described in the work.[10] A similar problem was solved in work[21] and a formula for welding current during spot welding was obtained. Spot welding is based on electromagnetic principles since a very powerful magnetic field is generated in the electrode core, as well as in the materials of worksheets, which is due to the flow of very high current. The final resulting effective current is a superposition of the welding current of the electrode and the induced eddy current in the aggregate part of the electrode.

3D finite element models of spot welds are also used to predict optimal welding conditions, including welding current strength.[22] Further processing of the analysis results with the use of the Taguchi method showed that the parameters of the electric current (22%) and the welding time (17%) are the most effective factors of influence the diameter of the welding point. For determining the adhesive strength, the pressing force was divided by the contact area of the overgrown layer with the ring-shaped part.[23]

$$\tau = F/S = \frac{F}{\pi d b}, \tag{6}$$

where F is the force on the axis of the part, N; S is the area of the adhesion ring, m^2; d is a diameter of a sample part, m; b is the adhesion ring width, m.

Figure 1 shows direction effort F from Equation (6) determined experimentally using a press of the P-125 type.

2.2 Equipment

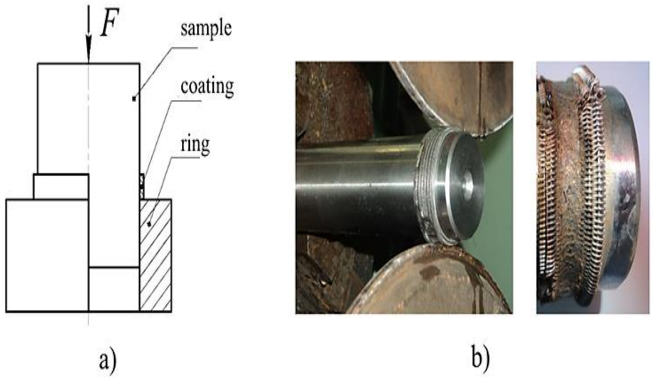
The installation of model 01-11.022 for electro-contact welding was used for welding gauze materials to samples. Taking into account the fact that most of the restored parts work under sliding friction conditions, and the restored layer is exposed to a shear force,[24,25] a shearing test of the strength of the adhesive to the base was studied according to the scheme on Fig. 1(a).

Samples made of Steel 45 with a diameter of 38-0. 02 mm were used as the part basis metal. Filler materials were welded for half a turn of the part (Fig. 1(b)). To strip the coating, the side surfaces of the welded layer were cut to a width of 4-5 mm. Samples prepared in this way were pressed through a hardened steel ring with a diameter of 38+0.01 mm using a press of the P-125 GOST 8905-73 type. The accuracy of the press readings was previously checked using a reference dynamometer DOSM-3-5 GOST 9500-75. The number of samples in one series is 5 pieces.

After cutting the coating on the P-125 press, the outer diameter of the uncoated sample b and the adhesion ring width i are determined using a caliper. The adhesion ring width is identified by the trace remaining from the cut coating. The obtained data are used in the formula (6) to get the value of the adhesion of the welded coating to the part.

The method of artificial bases was used to measure the wear of the overgrown layer. To do this, the samples were tested using the SMC-2 friction machine according to the "shaft-pad" scheme.[26]

The wear resistance of coatings obtained by electro-contact welding of gauze materials was studied using the SMC-2 friction machine and the artificial bases method. The method of artificial bases involves the determination of the quantitative value of linear wear by changing the size of a narrowing recess of a previously known profile made on the surface under study.



a) b)

Fig. 1 a) Scheme of the coating shearing test; b) Electro-contact welding of the steel gauze to samples for the strength adhesive testing.

In this case, the wear resistance is determined using the formula:[4]

$\Delta b = b_1 - b_2 = \frac{1}{z}(c_1 - c_2)$, this formula implies that

$$\Delta b = \frac{c_1 - c_2}{7} \tag{7}$$

where b_1 and b_2 are the print depths before and after the test, mm; c_1 and c_2 are the diagonals of the print projection on the test surface before and after the test; Z is the proportionality coefficient constant over the entire depth of the print if the print is made by a pyramid having the correct geometric shape, Z = 7 for the angle between the faces of the embedded pyramid $\alpha = 136^\circ$.

Prints for calculating wear values using Equation (7) are made with a Brinnel hardness taster.

The wear resistance tests of the samples were carried out according to the scheme (Fig. 2) "shaft-pad" using a well-known technique.

The basis of the roller samples (Fig. 2) was made of normalized Steel 45 GOST 1050-2013. Gray cast iron SCH15 GOST 1412-85 was adopted as the material for the abrasion pads. In order to obtain a complete fit of the mated surfaces, the pads were lapped using abrasive powder on a reference roller.

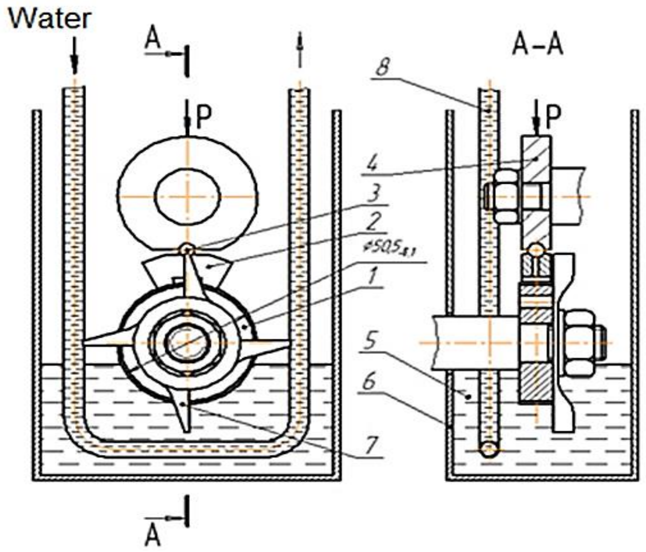


Fig. 2 The scheme of wear tests on the SMC-2 installation. 1- coated sample; 2- cast iron pad; 3- hardened steel ball; 4- stop on the carriage of the friction machine; 5- oil-abrasive mixture; 6- chamber body; 7- blades for mixing oil-abrasive mixture; 8- heat exchanger.

For determining the residual stresses in the coating layers of electro-contact welding, the method of penetration (Fig. 3) was used, which involves elastic-plastic contact interaction.

This method comprises correlating the identified dependencies of residual stress values with the movement of surface areas subject to deformation when exposed to the ball action.[27,28]

3. Results and discussion

Similarly, to other filler materials (steel tape, wire, metal powders), after electro-contact welding of gauze filler materials, the welded coating and the zone of thermal influence are characterized by structural heterogeneity manifesting in the hardness values fluctuation. This fluctuation is explained by the welding technology carried out along the helical curve by mutually overlapping points and rollers (Fig. 4). As a result, when the hardened area is reheated, the metal is released. Metal fall zones are visible in the macro-structural section (Fig. 5).

For electro-contact welding of quenching steel meshes, the hardness values measured by the Rockwell method range from 18 to 52 HRC, Table 1. The welding zone was cooled with running water during welding.

The measured coating hardness values obtained by electro-contact welding of the woven gauze made of Steel 45 (AISI 1045) are consistent with the hardness of the coatings obtained by electro-contact welding of the tape made of Steel 45 (AISI 1045). The difference in hardness is observed only in the smallest values. So, the lowest hardness values of the Steel 45 tape coating are HRC22, and the lowest hardness values of the Steel 45 (AISI 1045) gauze coating are HRC18 (Table 1). This decrease is probably due to the measurement of the hardness at the junction of the steel woven gauze.

Thanks to the hardness of the coatings obtained by electric contact welding of steel woven gauzes made of quenching

Fig. 3 Experimental installation for detecting residual stresses in the metal coating layer using the penetration method.

Table 1. Results of measuring the hardness of coatings obtained using electro-contact welding of gauze filler materials.

No	Filler material	Hardness	Electro-contact welding modes		
			Average current, kA	Current impulse duration	Time gap, s
1	Woven gauze with a cell edge of 4 mm inside width; Steel 45 (AISI 1045) gauze diameter is 1.6 mm	HRC 18…44	4.2	0.12	0.20
2	Woven gauze with a cell edge of 5 mm inside width; Steel 45 (AISI 1045) gauze diameter is 2 mm	HRC 20…40	4.1	0.12	0.20
3	Woven gauze with a cell edge of 2 mm inside width; St1 steel (A 283 Grade A) gauze diameter is 1.2 mm	HB 1240…1720	3.9	0.12	0.20
4	Woven gauze with a cell edge of 1.4 mm inside width; St1 steel (A 283 Grade A) gauze diameter is 0.45 mm	HB 1370…1510	3.6	0.12	0.20
5	Slotted wedge wire screen 14x88, d = 0,50/0,32 mm made of AISI 316 (DIN 1.4401) steel; 2 layers (domestic equivalent 03X17H14M2)	HB 1370…1710	4.1	0.12	0.20

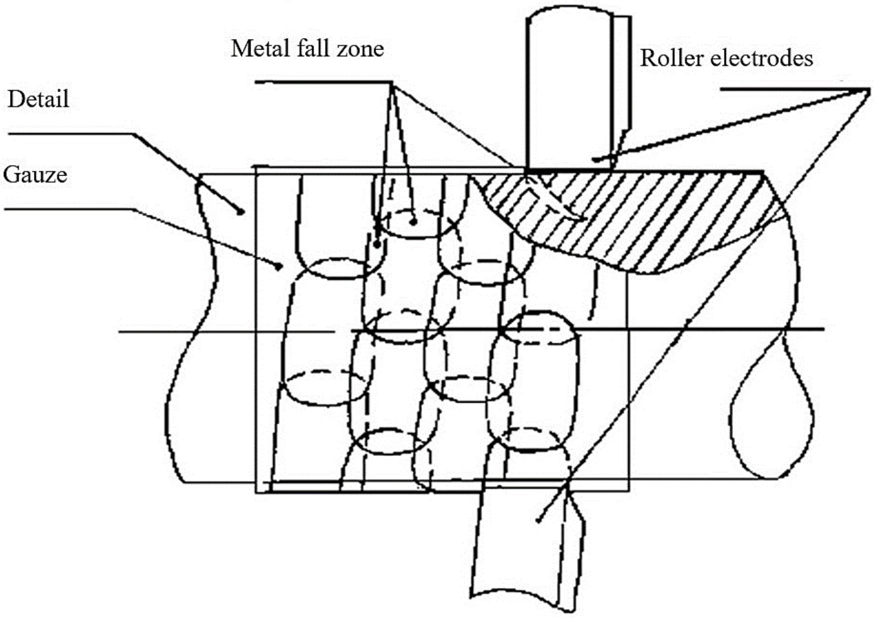


Fig. 4 Diagram of the weld spots' location during electro-contact welding.

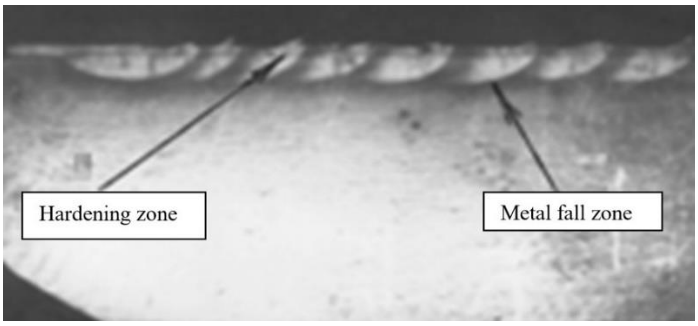


Fig. 5 Macrostructure of the part with the coating obtained using electro-contact welding of steel woven gauze.

steel, they can be used to restore worn parts experiencing sliding friction and operating with bushings and half-liners made of antifriction non-ferrous alloys. Coatings made of St 1 (A 283 Grade A) and St 2 (A53 Gr A) steel gauzes or other non-hardening steels can be used to restore the seats for ball bearings.

The calculation and measurement results of the coating thickness are presented in Table 1.

The coatings obtained from the materials listed in Table 1 are of high hardness except for gauzes made of A 283 Grade A steel. Therefore, it is necessary to use abrasive wheels or cutting tools with solid inserts for final cutting. Cutting modes are presented in papers.[29,30] The results of calculating the coating thickness h using the formulas (1) and (2) are comparable to the thickness of the coating layer when measuring the low spots of roller tracks, which proves that the calculations of the gauze sizes are correct.

Data on the specific mass per square meter of the slotted wage wire screen are not available (point 1 of Table 2), so it is impossible to calculate the coating thickness using formula (1).

Therefore, the calculated thickness of the coating was determined by the formula (2). The calculation results were compared with experimental data (Table 2). The comparison analysis revealed that the difference between the calculated and experimental thicknesses of the coatings is 3-20%, and the average values of the experimental data are very close to the calculated ones. For example, for a (Woven gauze: clearance – 1.4 mm, diameter – 0.45 mm, St1 steel (A 283 Grade A) in two layers), the calculated value of the coating thickness with a porosity of 0% was 0.36 mm. The average value of the experimental coating thickness along the depressions was 0.35 mm with a difference of 3%. For a porosity of 5%, the difference is 9%. For a (Woven gauze: clearance – 2 mm, diameter – 1.2 mm, St1 steel (A 283 Grade A)), the calculated value of the coating thickness with a porosity of 0% was 0.8 mm. The average value of the experimental coating thickness along the depressions was 0.7 mm with a difference of 14%. For the same mesh, but with a porosity of 5%, the difference is 20%. All the above allows the conclusion that the experimental coatings obtained by welding grids have no porosity. This is confirmed in the work.[10]

It can be guaranteed that the thickness of the overgrown coating layer will not be less than the value calculated according to formulas (1) or (2). The guaranteed thickness of the coating after mechanical grinding can be found by subtracting the allowance for machining from the calculated thickness (depending on the gauze size of 0.1-0.5 mm).

It can be concluded that using formulas (1) and (2), it is possible to calculate the pre-thickness of the build-up layer, which allows the effective selection of the proper gauze sizes for various wear rates.

Tests to determine the adhesive strength of coatings built up to gauze and tape using electro-contact welding (ECW) were made, and their results are as follows (Table 3).

According to the results of Table 3, there is not a large move up or down in the adhesive strength of different filler

Table 2. Values of coating thickness depend on different filler materials and electro-contact welding modes.

Item number	Variants of the filler material	Electro-contact welding modes			Resulting in coating thickness, h (mm)				
					calculated			experimental	
		current strength I, kA	current impulse duration t_{IE}, s	Time gap t_{pause}, s	according to the formula (1)	according to the formula (2) Porosity 0%	5%	in low spots	after grinding
1	Slotted wage wire screen14x88, diameter – 0.50/0.32 mm; AISI 316 steel in two layers (03KN17N14M2 analogue)	4.1	0.12	0.20	-	0.85	0.89	0.8	0.49
2	Woven gauze: clearance – 1.4 mm, diameter – 0.45 mm, St1 steel (A 283 Grade A) in two layers	3.6	0.12	0.20	0.31	0.36	0.38	0.3-0.4	0.16
3	Woven gauze: clearance – 2 mm, diameter – 1.2 mm, St1 steel (A 283 Grade A)	3.9	0.12	0.20	0.77	0.80	0.84	0.6-0.8	0.35
4	Woven gauze: clearance – 5 mm, diameter – 2 mm, Steel 45 (AISI 1045)	4.1	0.12	0.20	0.94	0.97	1.02	0.8-1.0	0.51
5	Woven gauze: clearance – 4 mm, diameter – 1.6 mm, Steel 45 (AISI 1045)	4.2	0.12	0.20	0.77	0.77	0.81	0.6-0.8	0.35

materials. Works[1,3] consider the strength properties of filler coatings obtained by electro-contact welding with the use of wire. Their results are consistent with the results of Table 3. In those works, the wear resistance of rollers that are worn out by the filler wire was achieved. In the case described in this paper, such a problem doesn't arise since the wear of the roller occurs evenly across the entire width of its working surface.

The modes of electro-contact welding have a strong influence on adhesive strength. The adhesive strength is directly proportional to the current strength, and current pulse duration, which is confirmed in work.[2] The adhesive strength of the filler materials based on the wires has comparable values in all modes and does not have large deviations. The optimal value of the current strength during electro-contact welding was studied in work,[10] while the temperature in the welding zone was studied as a parameter dependent on the current strength. The temperatures in the ECW zone in the mentioned work, and in the work described in this paper varied between 1100-1400 °C.

Table 3. Experimental results of coating adhesive strength.

No.	Material for the layer built up using electro-contact welding	Electro-contact welding modes			Results		
		Current strength I* (kA)	Current impulse t_{IE} (s)	Time gap t_{pause} (s)	Coating thickness h (mm)	Adhesive strength to the cut τ* (MPa)	Arithmetic mean deviation (MPa)
1	Woven gauze: clearance – 4 mm, wire diameter – 1.6 mm, 45 steel (AISI 1045)	5.60	0.20	0.20	0.60-0.80	318	52
2	Woven gauze: clearance – 2 mm, wire diameter – 1.2 mm, St1 steel (A 283 Grade A)	5.10	0.20	0.20	0.50-0.80	298	48
3	Slotted wage wire screen14x88, diameter – 0.50/0.32 mm; AISI 316 steel in two layers	4.90	0.20	0.20	0.80-0.90	297	61
4	Alloy wire NP-30ChGSA, wire diameter – 1.8 mm (AISI 3135)	5.10	0.20	0.20	0.40-0.50	313	59
5	Steel 45 (AISI 1045) tape 0.8 mm thick	5.40	0.20	0.20	0.50-0.70	392	26

Note: * – *mathematical expectation*

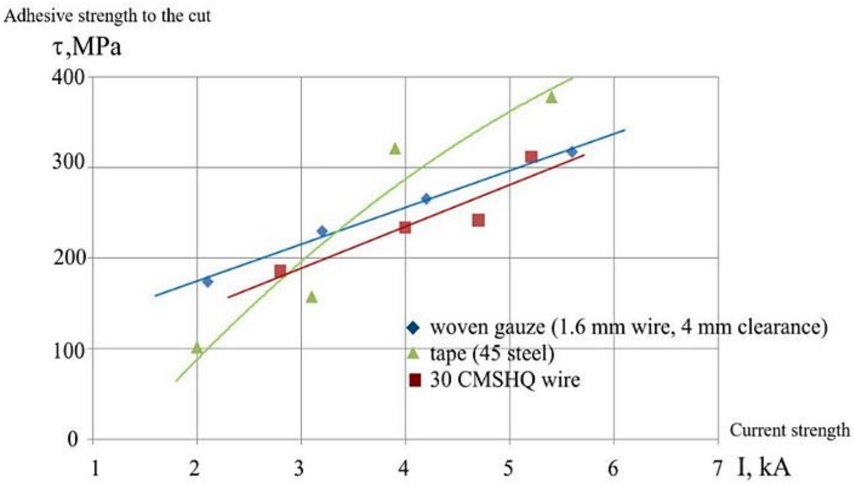


Fig. 6 Graph of the dependence of the adhesive strength of various filler materials during ECW on the current strength. CMSHQ – Chromo-Manganese-Silicon steel of high quality.

When comparing the adhesive strength of gauzes and wires (lines 1-4 (Table 3)) with the adhesive strength of steel tape (line 5), the following picture emerged. The adhesive strength of the Steel 45 tape (I = 5.4-5.6 kA, tim = 0.2 s., tpause = 0.2 s.) is 392 MPa, and the woven gauze adhesive strength (line 1) under similar conditions and a similar thickness of the coating layer will be 318 MPa (the difference is 19%). The situation changes at milder electro-contact welding modes (I = 2.0-2.1 kA, tim = 0.06 s, tpause = 0.08 s). Thus, the adhesive strength of the steel tape will be 102 MPa, and the woven gauze adhesive strength – 174 MPa (the difference is 41%). These results are shown more clearly in Fig. 6.

The graph shows that, when current strength increases, the adhesive strength of the overgrown layer during electro-contact welding of steel tape grows faster than during electro-contact welding of gauze or wire. This is due to the fact that at lower currents, electro-contact welding of steel tape is carried out in the solid phase. When the current strength is over 3.5 kA, a liquid phase is formed at the welding site.

The fatigue life of the parts, restored using electro-contact welding, depends on the endurance limit, which is higher when welding in the solid-plastic phase. At the same time, the adhesive strength of wire-based materials is 40±10% higher than that of steel tape layers, taking into account that all modes are the same. In work,[25] the obtained results show that during spot welding (RSW) of cemented carbide (WC–10Co) and high-strength steel (RM80), the shear strength of the welded joints first increases with the welding current, and then drops. The maximum strength during the optimal welding process is 924 MPa. Work[23] presents the results of the study on the adhesive strength of coatings, which were obtained by welding code wire consisting of various burden constituents. The results of the work prove that the strength of the proposed filler material (gauze) exceeds the adhesion of the sprayed code wire.

For contact spot welding of CR soft steel plates with a thickness of 1.25 mm (car body material),[31] the average tensile strength was 10.81 kN, with a welding point diameter of 5.26 mm, which corresponds to 498 MPa. Fig. 7 shows the wear graphs depending on the operating time for the layers built up using gauze and steel tape electro-contact welding.

The results of the conducted wear tests showed that the wear rate of the layer built up with the use of the slotted wedge wire screen was the highest. This is natural since the hardness

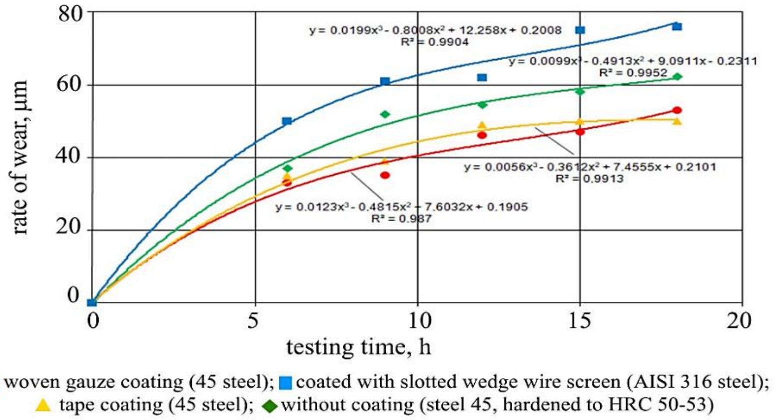


Fig. 7 The wear rate of coatings obtained by electro-contact welding via the testing time.

and wear resistance of the stainless steel from which gauze wire is made is lower than the reference surface of Steel 45 hard.

The wear resistance of the layers built up using electro-contact welding of woven gauze made from Steel 45 wire and Steel 45 tape, respectively, was higher than the reference surface made from 45 hard steel. Therefore, the use of gauze as a filler material is justified. Although the materials of the reference gauge and overgrown layer are the same, the wear resistance of the overgrown surface is 15% higher. The increase in wear resistance could be affected by the selective wear of a non-uniform zone of thermal influence of electro-contact welding.

In work[32] the wear resistance of three types of steel was compared: carbon Steel C45 (Steel 45), alloy steel 41Cr4 (Steel 40x analog), and martensitic stainless Steel GX3CrNi13-4 (03kh11n8m2f analog). The studies of all types of steel were conducted using a tribometer (CSM Tribometer), and the pin-on-disk (POD) method. The study proves that the wear resistance of C45 carbon steel is the highest, which is also confirmed by our research data.

The wear resistance of the obtained surfaces is lower than Ti-based surfaces,[33,34] but it is sufficient for the working conditions of the machine parts being restored.

The purpose of another study[35] was to compare C25 and C45 (Steel 25, 45) carbon steels, alloy Steel 34CrNiMo6 (30KHNML steel analog), and cast iron with spherical graphite EN-GJS-400-15 (RF 40 analog) using the same method. The obtained results confirm the increased wear resistance of the surface of Steel 45 in comparison to alloy steel. The surface of the cast iron sample is more wear-resistant since cast iron is an anti-friction material.

Any thermal action, including electro-contact welding, leaves residual stresses on the surface and subsurface layers (Fig. 8).

As in work[4], the value σ_θ/σ_T (the ratio of the effective stress to the yield limit of the sample material or coating) was used as the indicator of residual stresses. The following yield strength for the basic and filler materials was obtained (Table 4).

Table 4. Yield strength of materials.

Sample	Basic metal		Metal coating	
	Material	Flow limit σ_T, MPa	Material	Flow limit σ_T, MPa
1	AISI 1045 (45 steel)	300-340	Tape (45 steel)	310-370
2			FBH-6-2 powder	-
3			Woven gauze (45 steel)	310-370

The conducted experiments on residual stresses prove that the surface and subsurface layers of the overgrown filler materials have radial and tangential tensile residual stresses. The diagram in Fig. 8 shows the maximum value σ_θ/σ_T in electro-contact welding coatings of steel tape and powders (0.8 and 0.7 yield strength of the coating material, respectively). This occurs because compression deformations appear during electro-contact welding. When the temperature and deformation space-limited conditions decrease, residual tensile stresses appear. During spot welding, radial and tangential residual stresses correspond to the yield strength of the material. The tensile stresses are the stresses in the peripheral areas of the welding point, and the compressive stresses are the tangential stresses. This is not the case ~~of~~ with steam welding, which includes electro-contact welding when there are longitudinal tensile stresses instead of tangential stresses (they reach the yield strength of the material), and instead of axial, there are transverse tensile stresses, which are twice or four times lower than the longitudinal stresses. As for the near-weld area, here, the longitudinal stresses become compressive, and the transverse stresses remain tensile.

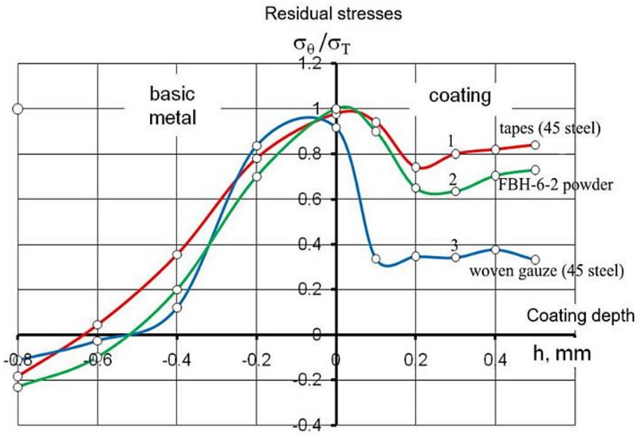


Fig. 8 Value of residual stresses σθ/σT according to coating depth h of electro-contact welding.

Figure 6 shows that the residual stresses in the layer built up using electro-contact welding of woven gauze (C) are minimal compared to the stresses of other presented materials. This is due to the fact that during the thermal and mechanical action of the roller on the gauze, when it is welded, there is a space for the deformation of both longitudinal and transverse gauze wires. During electro-contact welding of wire, the residual stresses are higher (b). Reducing residual stresses increases the fatigue resistance of parts restored with the use of electro-contact welding of both gauzes and wires. To increase the fatigue resistance after electro-contact welding, a method of subsequent heat treatment of the welded coating is proposed in the work.[36,37]

When comparing residual stresses in the coating obtained using electro-contact welding of steel wire[4,27,28] with the residual stresses during electro-contact welding of gauze materials,[38] it can be concluded that the use of wire as a filler material provides lower residual tensile stresses compared to the use of steel gauze. This can be explained by a decrease in the degree of deformation of the gauze material compared to the wire.

Gauze, as a proposed filler material and developed rational modes of its electro-contact welding, was implemented for the restoration of automotive parts in the "Bashselkhoztekhnika" State Unitary Agricultural Enterprise. Implementation of the proposed technology in "Turbasly Broilers" Open Joint-Stock Company allowed ~~to~~ the restoration of the plungers of washing machines economizing 175,000 rubles per year, while the annual recovery program involves 150 pieces.

4. Conclusion

When using electro-contact welding of hardening steel gauzes, the hardness values are HRC18...52. This variation is explained by the technology of contact welding carried out along a helical line by mutually overlapping points. The use of various gauze types as an additive material has shown that the thickness of the deposited metal coating layer can be calculated according to formulas (1) and (2) depending on the gauze parameters. The minimum difference between the calculated and experimental values of the coating thickness with a porosity of 0% is 3%, and the maximum is 14%. For a porosity of 5%, the difference is 20%. Experimental coatings obtained by gauze welding have no porosity. The adhesive strength of the Steel 45 tape (I = 5.4-5.6 kA, tim = 0.2 s, tpause = 0.2 s) is 392 MPa, and the adhesive strength of the woven mesh under similar conditions and similar thickness of the coating layer is 318 MPa (19% difference). With milder modes of electro-contact welding (I = 2.0-2.1 kA, tim = 0.06 s, tpause = 0.08 s), the adhesive strength of the steel tape is 102 MPa, and the woven mesh – 174 MPa (the difference is 41%). The wear resistance of the studied welded gauze coatings (Steel 45) is 15% higher than the wear resistance of the uncoated sample (Steel 45). This fact was influenced by selective wear of the inhomogeneous zone of thermal influence of electro-contact welding. Residual tensile stress in steel gauze coatings is 56% lower than when using steel tape. This is due to a decrease in the degree of deformation of the mesh material compared to steel tape. The results of the study were used to implement the technology for the restoration of automotive parts, which helps effectively restore parts and save on the cost of purchasing new ones.

Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

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