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RESEARCH OF WEAR AND INCREASING WEAR RESISTANCE OF THE WORKING PART OF BUSBAR PUNCHING TOOLS BY SURFACING METHOD

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This article aims to establish the cause of wear and select a surfacing method to increase the wear resistance of the working part of the busbar punching tool. A study was carried out on existing methods for increasing the wear resistance of working surfaces of parts and tools operating under heavily loaded thermodynamic conditions, as well as under high contact and impact loads. As a result of the data analysis, the ESAB OK Tubrodur 35GM surfacing wire and the mechanized surfacing method using a protective gas environment were selected for surfacing the working part of the busbar punching tool. An experiment was planned to determine the number and parameters of experiments that will allow achieving the required level of accuracy to obtain the necessary information about the object of study. Calculations made during the experiment's planning resulted in a multiple regression equation that determines the dependence of the deposited layer's hardness on the current strength, welding voltage, and the speed of movement of the welding torch. The optimal operating parameters for surfacing samples in shielding gases were determined using the MATLAB software package. The research, the results of which are presented in this article, is funded by the Committee on Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (grant № AP19578884 "Increasing wear resistance and improving the design of the tool of the busbar punching machine").

Keywords: busbar punching tool, wear, wear resistance, surfacing, hardness

1 INTRODUCTION

Mechanical engineering is an integral part of the economy's industrialization and the most important sector of the state. The industry ensures the stability of the agro-industrial complex, energy and metallurgical sectors, transport, and other key industries, which largely determine the economy's material intensity, labor productivity, and economic security.

Over the past 10-15 years, the industry has moved from producing components and spare parts to producing final products. Today, technical re-equipment of production is actively taking place at many machine-building enterprises of the Republic of Kazakhstan (RK). The outdated machine park for machining and other types of metal processing (casting, heat treatment, metal forming, etc.) is being updated. Imported machines follow technology development, which allows us to maintain production quality at a high level. One of which is busbar punching presses. These machines are currently widely used at such plants as Elektromontazh JSC, Astana Electromechanical Plant LLP, KazElectroSystems Electrical Equipment Plant LLP (Astana, Kazakhstan), Ural Transformer Plant, Almaty Electromechanical Plant LLP, LLP "Asia Trafo" - Alageum Electric (Shymkent, Kazakhstan), JSC "Kentau Transformer Plant - Alageum Electric" (Kentau, Kazakhstan), etc. for punching holes on transformer busbars. Figure 1 shows busbar punching presses.

Studies carried out in the conditions of the above-mentioned factories showed that the tire-punching tool is subject to intense wear and chipping. According to operating conditions, the punch tool and dies are classified as heavily loaded tools since they are in contact with the metal being pressed. The pressing process occurs at high temperatures, pressures and intense friction. The main reason for the intense wear of the punching tool is overheating, which decreases the strength and, in turn, leads to deformation. In particular, wear of the matrix occurs when its temperature during pressing exceeds the tempering temperature, which can lead to its plastic deformation. The operating conditions of the tool have a great influence on its durability. In most cases, the pressing process is not smooth; shock loads on the tool require high limits of impact strength from the tool material, which can be difficult to combine with its high hardness. Impact loads reduce the durability of the pressing tool. Abrupt release of pressure, which can be avoided, leads to tool failure. Prolonged exposure of the tool to high temperatures (850°C for copper and 1100°C for steel) sharply reduces its durability. In this regard, this tool is replaceable and provides improvements to these designs to increase productivity and reduce the cost of pressing tools. Figure 2 shows worn punching tools.

a) b)

Fig. 1. Busbar punching machines-presses: a, b – busbar punching machines-presses of the DMZ-303K series

a) b)

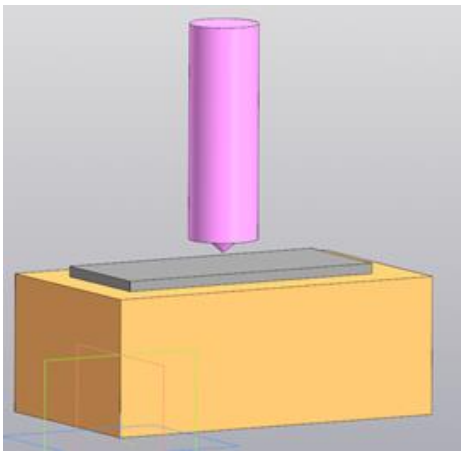
c) d)

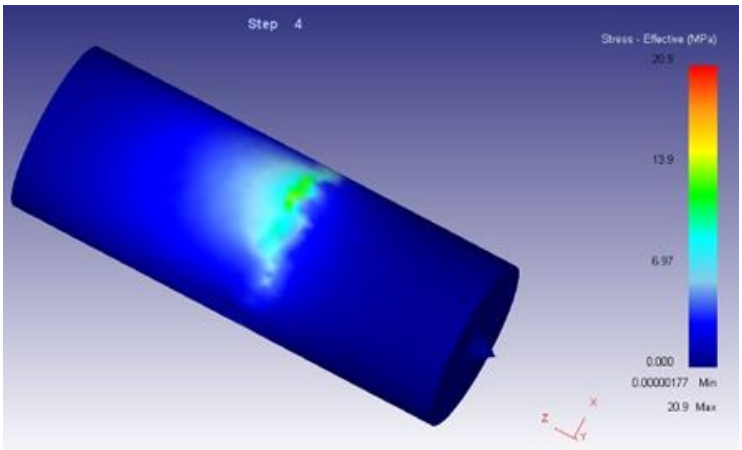
Fig. 2. Worn busbar punching tools: a – busbar punching tools; b – punches; c, d – assembled busbar punching tools; 1 – busbar punching tool; 2 – punch; → - wear and chips

A finite element study using the Deform 3D package was performed to clarify the cause of fractures in the punching tool's body [1,2].

The workpiece model was made according to factory drawings in the Siemens NX environment. The process parameters are taken in accordance with the busbar punching machine's passport. When modelling in Deform, the following process conditions were specified: tool and workpiece material, friction coefficient, and tool speed.

Figure 3 shows the modeling process in Deform 3D [2].





a) b)

Fig. 3. Modelling process in Deform 3D: a – models of the tool, busbar and matrix; b – stress distribution in the tool body

Analysis of the modelling results in Deform 3D showed that at the initial stages of the process, compressive stresses predominate and reach a value of 200 MPa [2]. During the deformation process, as a result of the material's movement towards the matrix's walls, the stresses become compressive. It was found that an increase in tensile stresses and an increase in deformations occur precisely in the place where wear or breakage is detected in real production.

This state of the problem dictates the need to develop technology to increase the wear resistance of the working part of the busbar-punching tool structure, and scientific research aimed at solving this problem is relevant.

When designing technological processes for manufacturing impact-resistant tools, special attention is paid to ensuring the wear resistance of the working part of the tool, which is subjected to shock loads and high pressure in the contact area with the workpiece. Studies have shown that various methods are used to increase the wear resistance and impact resistance of tools and technological equipment.

Navas et al. [1] highlight the use of cladding methods for stamp restoration using a continuous-wave diode laser. In addition, due to the high cost of raw materials and the difficulty of producing titanium alloys, Wei Gao et al. [3] successfully deposited a thin titanium alloy coating on the surface of low-carbon steel by laser cladding and found that the laser cladding speed is a critical parameter for tuning the characteristics coverings.

A method is also known to be changing the chemical surface material of the surface combined with heat treatment to improve its wear resistance, hardness, and other performance characteristics. These processes involve saturating the surface layer of the metal with various elements, such as carbon, nitrogen, boron or chromium [4]. In the research of Widomski et al. [5], a wear method for tools designed for hot stamping processes and a technology for increasing wear resistance was proposed, which was achieved through thermochemical treatment through nitriding and hybrid layers. In addition, various nitriding methods were applied, and the influence of the phase structure of the nitrided layer was studied.

Under such conditions, especially during intensive use, the wear resistance of tools may be insufficient due to the heterogeneity of the microstructure and retained austenite.

Therefore, many scientific works have been devoted to increasing the operational stability of various products. One of these works aimed to study the effect of isothermal hardening from the intermediate zone and the duration of deep cryogenic treatment on structure formation and wear resistance [6]. Isothermal hardening promotes the formation of the required multiphase microstructure of steel. Complex heat treatment of steels according to the proposed regime makes it possible to achieve significant decomposition of retained austenite to martensite, which leads to increased wear resistance.

In the work [7], a study of the surfacing process of thermal friction tools was carried out in order to increase their wear resistance. The electric arc welding method was used to apply surfacing. The methodology for studying the hardness of deposited layers is based on experimental and metallographic research methods. Analysis of existing surfacing materials showed that surfacing materials STOODY M7-G, STOODY 102-G and OK TUBRODUR 58 O/G M have high hardness, wear resistance and temperature resistance. The study results showed that all three surfacing materials retain their original hardness during two-layer surfacing. It was established that from the middle of a single-layer surfacing to the end of a two-layer surfacing, the value of the hardness of the surfacing does not change. It has been established that two-layer surfacing is sufficient for surfacing the cutting part of thermal friction tools. In this case, the thickness of the first and second layers should be 4 and 2 mm, respectively.

The work [8] proposes a method of frictional surface hardening of spherical surfaces of machine parts. The process is carried out due to the friction of the tool and the workpiece in contact, where pulsed heating of the processed surface occurs to a temperature of 800...1000°C. Rapid cooling of the surface being hardened occurs due to the coolant supply to the processing zone. As a result, structures of white layers with a thickness of 0.1...0.15 mm with an increased microhardness of 7...10 GPa appear on the hardened surface of the workpiece.

In works [9,10], a combined technology was developed to increase the wear resistance of parts of an automatic coupling device operating under constant friction and sudden impacts. Wear-resistant surfacing material SURRADUR 400B is deposited onto the worn surfaces of the parts, and the deposited surface is processed by two methods of thermal friction milling - traditional thermal friction milling and thermal friction milling with pulse cooling. With both processing methods, an increase in the initial hardness of the treated surface was achieved within the range of 1÷7%, which is, respectively, 10÷60 HB. However, it is noted that when thermal friction milling using a smooth friction cutter, a higher hardness (HB480) of the machined surface was achieved.

After analyzing existing methods for increasing the wear resistance of the working surfaces of parts and tools operating under heavily loaded thermodynamic conditions and high contact and impact loads, the method of mechanized surfacing using a protective gas environment was chosen.

The scientific novelty of this paper lies in the establishment of optimal surfacing modes that make it possible to ensure the quality of surfacing while maintaining the original properties (hardness, wear resistance) of the surfacing material. And also the novelty lies in the identification of a multiple regression equation that determines the dependence of the hardness of the deposited layer on the surfacing modes. Of scientific and practical interest is also the use (for the first time) of the method of mechanized surfacing using a protective gas environment for surfacing the material of a busbar punching tool. Since this tool is manufactured by foreign manufacturers and there is no information about its material. The research we conducted to determine the material of the tool showed that its chemical composition is very different from related materials that are used in our domestic industries.

2 MATERIALS AND METHODS

The method of mechanized surfacing using a protective gas environment was chosen for surfacing prepared samples. The area of application of surfacing in shielding gases is the restoration of a wide range of parts (axles, axles, shafts, etc.), as well as welding parts made of cast iron, aluminum alloys, thin sheet steel, etc. Surfacing in a shielding gas environment consists of the following: The electric arc combustion zone is supplied with shielding gas under pressure, which isolates the arc column and the molten weld pool from oxygen and nitrogen in the air.

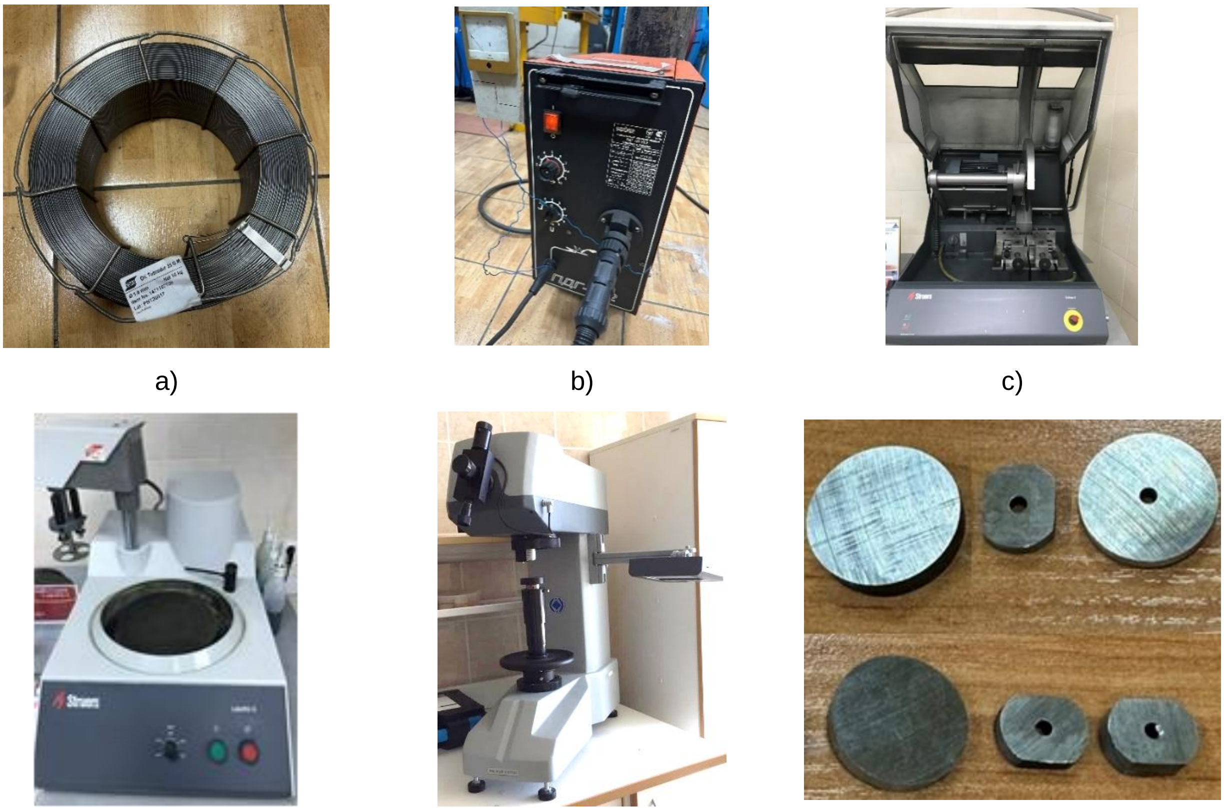
The main advantages of welding and surfacing in shielding gases are good use of the heat of the welding arc, which ensures high productivity; the possibility of mechanization and automation of welding and surfacing processes of parts located in any spatial position; high quality of welded (overlaid) seams; possibility of monitoring the progress of welding (surfacing); possibility of welding (surfacing) of parts of any thickness; there is no need to clean the seam from slag, which is especially important for multi-layer surfacing. Disadvantages: increased metal spattering (up to 10…12%); limited alloying of the deposited metal (only through the electrode wire); reduced wear resistance; reduction in fatigue strength (by 10...50%).

The welding materials used for surfacing in shielding gases are surfacing flux-cored gas-shielded welding wire.

ESAB OK Tubrodur 35 GM, 1.6 mm in diameter, providing low-alloy martensitic steel in the deposited layer, intended for restoration surfacing in workshop conditions of worn surfaces operating under conditions of intense metal-to-metal friction under high contact and impact loads. It is used for hardening the surfacing of crane and conveyor wheels, shafts, gear teeth, axles, rollers, pins and tracks of mine tractors. It can be used to restore the working surfaces of cast hammers and beaters, and when restoring the teeth of buckets and excavators, the body of the tooth is fused to it before hardening surfacing.

The chemical composition and mechanical properties of the wire are similar to tool steel. It can be machined with carbide tools. Direct current of reverse polarity (DC+) with straight rollers or oscillations is recommended. Adding CO_2 shielding gas when welding with 1.6 mm wire reduces spatter. Multi-layer surfacing is permitted as long as proper preheating and interpass temperatures are maintained. Typical chemical composition: Alloying elements – 13% (chrome, manganese, molybdenum, silicon, carbon).

The surfacing process was carried out on a semi-automatic welding machine PDG-252, designed for arc welding with a consumable electrode using direct current in a shielding gas environment. Figure 4 shows the materials and equipment used.



a) b) c)

d) e) f)

Fig. 4. Used materials and equipment: a – ESAB OK Tubrodur 35 GM; b – semi-automatic welding machine PDG-252; c – automatic desktop cutting machine UNITOM-2; d – automatic machine for grinding and polishing LABOPOL-5; e – hardness tester WILSON VH1150; f – samples from busbar punching tools

The hardness of the deposited surfaces was measured using the equipment of the engineering testing laboratory “Complex Development of Mineral Resources” and the International Center for Materials Science of the Saginov Technical University (Fig. 4, c,d,e).

3 EXPERIMENTAL STUDIES

3.1 Planning a Surfacing Experiment

Experimental planning consists of determining the number and parameters of experiments that will achieve the required level of accuracy to obtain the necessary information about the object of study. One of the essential requirements for a scientifically conducted experiment is to minimize the number of experiments performed, which in turn helps to save material, labor and time resources [11,12,13,14].

The purpose of planning the experiment is to confirm the assumption that the hardness of the deposited layer changes depending on the surfacing modes, such as current strength, welding voltage and wire feed speed. An experimental plan is drawn up to determine the dependence of the hardness of the deposited layer (Y) on the current strength (X1), welding voltage (X2) and the speed of movement of the welding torch (X3)

Input variables (Xi) that determine the object's state of study are called influencing factors. Their main criterion is to ensure effective control, which implies the ability to set a given level of a factor and maintain its stability throughout the experiment.

The output variable Y is the reaction of the research object to the influencing factors - the response function. The hardness of the deposited layer was chosen as the output parameter. The hardness of the weld deposit plays a key role in many technical and industrial applications. A harder deposit provides better resistance to wear and abrasion. Also, the hardness of the deposited layer can influence other mechanical properties such as strength, fatigue life and toughness. This can be a critical factor when designing and manufacturing parts subject to dynamic loads.

Next, to draw up an experimental plan, we determine what value each factor should take in each experiment. The planning matrix is a table containing the values of factors for each experiment conducted. It includes both independent and dependent factors. The part that includes independent factors is called the experimental design. An experiment in which all possible combinations of factor levels are performed is a complete factorial experiment.

For the convenience of processing the experimental results, it is advisable to present all factors in dimensionless form, for which we carry out the operation of encoding variables. With this encoding, all new variables will take values from -1 to +1. The primary interval level in which the experiment is supposed to be conducted is taken as the zero level. After coding, the experiment planning matrix will have the form presented in Table 1.

Table 1. Experiment planning matrix

Code	X_1	X_2	X_3	Pair interactions			Hardness, HV
				X_1X_2	X_2X_3	X_1X_3	
1	145	17,5	9	+	+	+	365
2	180	18,5	10	-	-	+	370
3	200	20	11	-	+	-	384
4	220	21	12	+	-	-	401
5	230	22	13	+	-	-	415
6	240	23	14	-	+	-	433
7	250	24	15	-	+	+	445
8	260	25	16	+	-	+	470

Table 2 shows the values of factors and their levels.

Table 2. The values of factors and their levels

Variation parameters	Factors		
	Current strength I, A (X_1)	Welding voltage U, B (X_2)	Torch travel speed v, cm/min (X_3)
Main level	202,5	21,25	12,5
Variation interval	57,5	3,75	3,5
Top level	260	25	16
Lower level	145	17,5	9

The theoretical linear multiple regression equation considered in this mathematical model can be represented as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i \tag{1}$$

The least squares method was used to determine the regression coefficients. For further calculation, it is necessary to calculate the matrices with the previously selected influencing and influencing parameters. After completing all matrix calculations, a regression equation can be derived, which will be used to check the adequacy of the model and create a mathematical model that meets the requirements. Therefore, the regression equation is as follows:

$$Y = 26{,}992 + 0{,}785X_1 + 34{,}568X_2 - 43{,}08X_3$$

Most often, the quality of the resulting regression model is assessed by the values of the average error of approximation and the coefficient of determination. This is a simple coefficient that briefly reflects how well the simulated process matches the real one and is calculated using the formula:

$$A = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{y_i - \hat{y}_i}{y_i}\right| \cdot 100\% \tag{2}$$

where, y_i – actual value of attribute Y; $y^{\wedge}_i$ – conceptual value of attribute Y, found using the regression equation; n – number of experiments.

$$A = 4{,}78\%$$

It is generally accepted that if any of these errors do not exceed 12%, then the regression model is considered to be of good quality, i.e., adequate to reality, and realistic forecasts can be made from it.

Let us determine the correlation values of the model parameters. Accordingly, a matrix is compiled containing the value of the variables Y and X. To determine the numerical value of paired correlation coefficients and an equation is used that is:

$$r_{xy} = \frac{\overline{xy} - \overline{xy}}{s(x)s(y)} \tag{3}$$

Using this equation, the linear relationship coefficient between the remaining parameters X and the dependent Y, as well as between the parameters X themselves, is determined.

After completing all the calculations of paired correlation coefficients, you can display general information in Table 2, which is a visual representation of the degree of influence of the parameters on the dependent variable and on each other.

Table 3. Values of pair correlation coefficients R

	Y	X_1	X_2	X_3
Y	1	0,894	0,924	0,969
X_1		1	0,912	0,916
X_2			1	0,989
X_3				1

The selected parameters have a strong linear relationship when receiving a numerical value of -1 or 1. As seen from Table 2, almost all selected parameters of the surfacing mode have a strong linear relationship with the hardness index of the deposited layer, which proves the possibility of the input parameters influencing the dependent variable.

The multiple correlation indicator characterizes the closeness of the connection between the set of factors under consideration and the characteristic under study or, in other words, assesses the closeness of the joint influence of factors on the result. This statistic is useful when performing multivariate regression (using multiple independent variables) when describing the relationship between variables. The limits for changing the multiple correlation index are from 0 to 1.

If factors are correctly included in the regression model, the value of the multiple correlation index will differ significantly from the pairwise correlation index. If the factors additionally included in the multiple regression equation are tertiary. The multiple correlation index can practically coincide with the pair correlation index (differences in the third and fourth digits). From here, it is clear that by comparing multiple and pair correlation indices, we can conclude that it is advisable to include one or another factor in the regression equation [11,12,13].

The multiple correlation coefficient can be determined through the matrix of paired correlation coefficients:

$$r_{yx_i} = \sqrt{1 - \frac{|Q|}{Q_{11}}} \tag{4}$$

where Q is the determinant of the matrix of paired correlation coefficients;

Q_{11} – determinant of the interfactor correlation matrix.

$$r_{yx_i} = \sqrt{1 - \frac{1{,}9318}{0{,}00348}} = 0{,}997$$

The closer its value is to 1, the closer the connection between the effective attribute and the entire set of factors under study.

Next, we check the significance of the multiple correlation coefficient, which, as in pairwise regression, is assessed using the Fisher F test. The F-statistic is a value used in various statistical tests, including regression analysis, to determine if the variances between populations or the overall fit of a model are significant. In regression analysis, the F-statistic is used to test the null hypothesis that all regression coefficients are equal to zero (meaning the predictors do not explain any of the variability in the dependent variable).

In this case, the F-criterion's actual (observed) value is calculated through the coefficient of determination R^2, calculated from the data of a specific observation.

$$F = \frac{R^2}{1 - R^2} \cdot \frac{n - m - 1}{m} = 23{,}9$$

where R^2 is the coefficient of determination, $R^2 = r_{yx}^2 = 0.994$.

The critical value of the F test is determined based on the specified significance level and degrees of freedom.

$$F_{cr} = F(m; n - m - 1) = F(3;4) = 6{,}59.$$

If the calculated F-criterion's value exceeds the critical value ($F > F_{cr}$), it generally indicates that there is a statistically significant difference between the groups being compared and the independent variables, collectively, provide a good fit for predicting the dependent variable. The null hypothesis (which states that all group means are equal) is rejected.

3.2 Experimental Studies on Surfacing Samples and Hardness Measurements

Surfacing of the samples was carried out in the laboratories of the Welding Institute of the Abylkas Saginov Karaganda Technical University. Surfacing modes are given in Table 4.

Table 4. Values of pair correlation coefficients R

Mode options	ESAB OK Tubrodur 35 GM, Ø1,6 mm		
	Sample No.1	Sample No.2	Sample No.3
Input parameters			
Welding current strength, A	200	230	260
Welding voltage, V	20	23	25
Welding torch travel speed, cm/min	10	13	15
Output parameters			
Height of deposited layer, mm	2,46	3,87	3,02
Penetration depth, mm	2,12	1,94	1,12
Hardness of the deposited layer, HV	425	459	415

Figure 5 shows the surfacing process of the samples.

a) b) c) d)

Fig. 5. The surfacing process of the samples: a, b – the beginning of the process; c – surfacing process; d – completion of the surfacing process

Figure 6 shows the deposited samples.

a) b) c)

Fig. 6. The deposited samples: a – sample No.1; b – sample No.2; c – sample No.3

The samples were cut in the middle into two equal parts. A cutting machine, UNITOM—2, was used for cutting (Fig. 4, c). An automatic LABOPOL-5 machine was used to grind and polish the samples (Fig. 4d). The grinding process was carried out in four stages: levelling, fine grinding, diamond polishing, and oxide polishing. After grinding, hardness was determined using a WILSON VH1150 hardness tester (Fig. 4, e). Figure 7 shows sections of the samples after hardness measurements.

a) b) c)

Fig. 7. Sections of samples after hardness measurement: a – sample No.1; b – sample No.2; c – sample No.3

Hardness measurements were carried out according to the scheme shown in Figure 8.

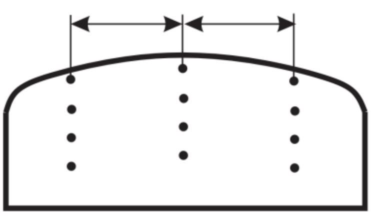


Fig. 8. Hardness measurement scheme

The obtained hardness measurement results were entered into Table 5.

Table 5. Hardness measurement results

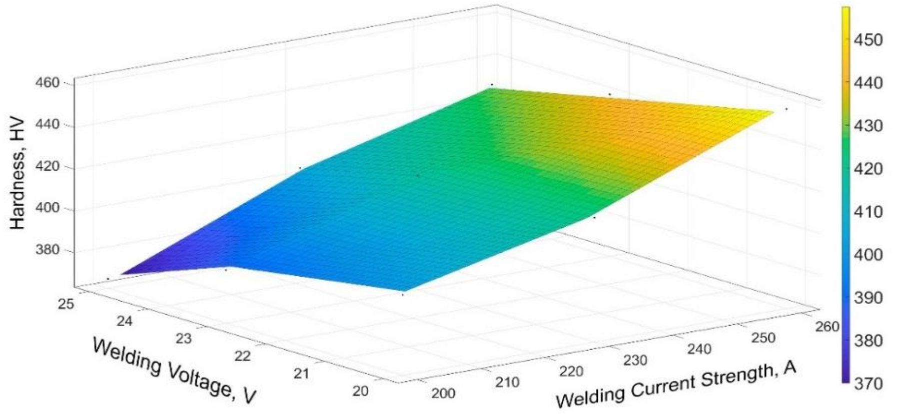
Sample No.1			Sample No.2			Sample No.3		
Meas.1, HV	Meas.2, HV	Meas.3, HV	Meas.1, HV	Meas.2, HV	Meas.3, HV	Meas.1, HV	Meas.2, HV	Meas.3, HV
467	465	467	458	464	468	456	459	462
458	449	455	442	445	439	444	449	430
392	385	399	368	377	358	395	382	392
295	289	253	251	248	240	276	264	259

The hardness of the deposited layer was measured, and experimental data was processed based on the results.

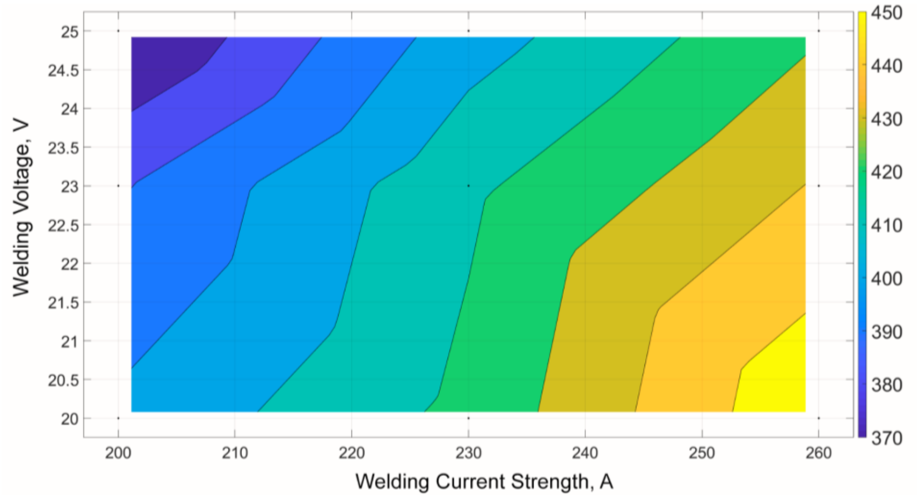
3.3 Determination of Optimal Surfacing Modes

The MATLAB software package was used to construct the response surface and determine the optimal surfacing mode. The MATLAB software package provides extensive capabilities for performing mathematical calculations, visualization, and programming. MATLAB visualization tools allow you to create 2D and 3D plots to visualize your data.

Response surfaces were constructed to determine the optimal surfacing mode: the dependence of the hardness of the deposited layer on the strength of the welding current and welding voltage (Fig. 9), the dependence of the hardness of the deposited layer on the strength of the welding current and the speed of movement of the welding torch (Fig. 10).

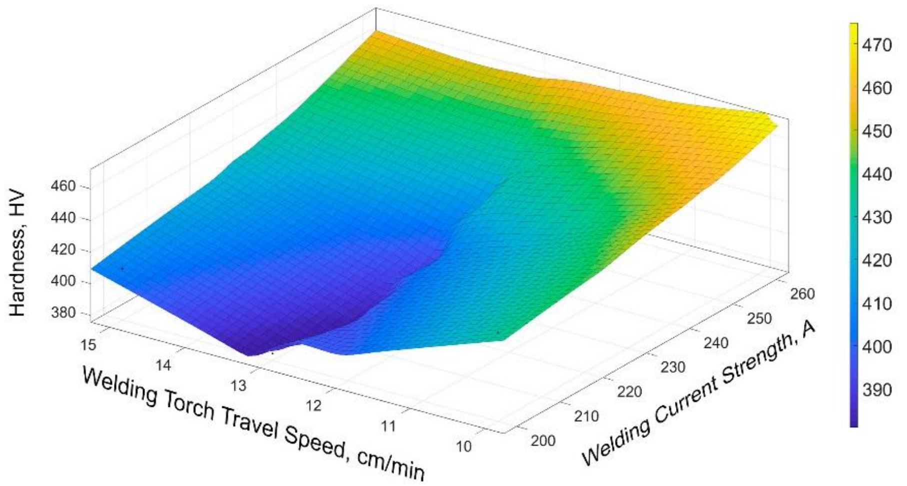


a)

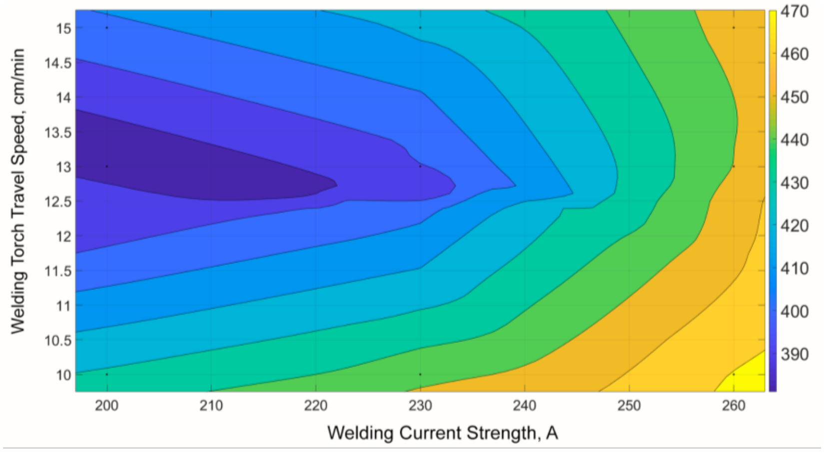


b)

Fig. 9. Dependence of the hardness of the deposited layer on the strength of the welding current and welding voltage (a) and a contour graph of the hardness (b)



a)



b)

Fig. 10. Dependence of the hardness of the deposited layer on the strength of the welding current and the speed of movement of the welding torch (a) and a contour graph of the hardness (b)

4 RESULTS AND DISCUSSION

The experimental study confirmed the assumption that the hardness of the deposited layer varies depending on the surfacing modes, such as current strength, welding voltage, and wire feed speed.

In the course of the analysis of response surfaces, the following optimal operating parameters for surfacing samples in shielding gases were determined:

- welding current strength – 260 A
- welding voltage – 20 V
- surfacing speed – 13 cm/min.

At the same time, the hardness fluctuated between 390 and 470 HV. The highest hardness value corresponded to the optimal operating parameters (Fig. 10, a, b). The highest hardness value in experimental studies was HB 468 (Table 2). If we compare the experimental data (468 HV) with the data (470 HV) obtained in the MATLAB software package, the deviation is 1.5%.

As a result of calculations when planning the experiment, a multiple regression equation was obtained:

$$Y = 26{,}992 + 0{,}785X_1 + 34{,}568X_2 - 43{,}08X_3$$

Interpretation of model parameters: An increase in X_1 by 1 unit leads to an increase in Y on average by 0.785 units; an increase in X_2 by 1 unit leads to an increase in the decrease in Y by an average of 34.57 units; an increase in X_3 by 1 unit leads to a decrease in Y by an average of 43.08 units.

The equation's statistical significance was tested using the coefficient of determination and Fisher's test. The result shows the coefficient of determination's statistical significance and the reliability of the regression equation.

5 CONCLUSIONS

Studies carried out in machine-building plants have shown that busbar punching tools are subject to intense wear and chipping. It was revealed that the main reason for the punching tool's intense wear is overheating, which decreases its strength, which, in turn, leads to deformation. In particular, wear of the matrix occurs when its temperature during pressing exceeds the tempering temperature, which can lead to its plastic deformation.

It was experimentally established that the method of mechanized surfacing using a protective gas environment could be used to increase the wear resistance of the working surfaces of parts and tools operating under heavily loaded thermodynamic conditions, as well as under high contact and impact loads. As a result of the calculation, when planning the experiment, a multiple regression equation was obtained that determines the dependence of the hardness of the deposited layer on the current strength, welding voltage and the speed of movement of the welding torch.

6 ACKNOWLEDGMENT

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