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TECHNICAL AND TECHNOLOGICAL IMPACTS ON METAL CRYSTALLIZATION DURING AUTOMATIC AND MECHANIZED ELECTRIC ARC WELDING-SURFACING

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Summary *The generalized systematization of application of systems and means of the welding equipment on the basis of mechatronic and mechanical designs concerning maintenance of operational characteristics of welds and the welded layers at electric arc welding-surfacing by a melting electrode is offered. It is shown that the improvement of the mechanical properties of the welded joint can be obtained by introducing new components and parts into the standard equipment. The estimation of technical and technological actions in the process of welding for formation of purposeful influence on conditions of crystallization of metal of a pool is given.*

Key words *systematization, arc welding, melting electrode, welding-surfacing, crystallization, impulse motion.*

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Statement of the problem. Electric arc welding and melting electrode surfacing is one of the main methods that exist and will remain for both creating new structures and restoring and strengthening of currently operating nodes and parts of various purposes [1]. The necessary technical and technological actions affecting the crystallization of the pool in the process of electric arc welding, as a result, allow forming the desired strength properties of the weld metal and deposited metal layers, which provide the necessary operational characteristics of the products. Therefore, research on determining the constructions of welding and surfacing equipment systems, the use of which forms such actions, is relevant.

Analysis of available investigations. One of the main problems of electric arc welding and surfacing with an electrode wire is to ensure such properties of the weld and the surfacing roller that allow solving the task of strengthening necessary to obtain the desired operational characteristics of the product as a whole. This fully applies to the use of automatic and semi-automatic equipment designed for both welding and surfacing with solid and powder electrode wires in the environment of protective gases and under flux. When creating new welding equipment, specialists mainly focus on the development of node designs, the use of which increases the strength σ_τ and yield strength σ_B, as well as plasticity and fracture toughness. Herewith, it can be noted that some indicators, in particular the yield strength σ_B, also determine the reliability of the structure.

It is known that physical and mechanical indicators of metal strength also depend on the influence of technical and technological actions in the welding process.

Generalized estimation of the impact of such actions will allow purposeful selection of equipment to solve a specific welding task.

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Studies [1, 2] do not contain generalized estimation of the influence of technical and technological actions on the crystallization of the pool metal during automatic and mechanized electric arc welding-surfacing with a melting electrode, but only provide conclusions on the analysis of such influence on some physical and mechanical parameters of the metal obtained from joints of welded structures.

The objective of the study is to obtain a generalized estimation of the impact of welds and deposited layers formed during welding and surfacing by various systems and methods on physical and mechanical parameters and on the metal structure.

Statement of the purpose. To systematize the existing systems and methods of electric arc welding and surfacing using a melting electrode for estimation of the strength of welded joints and surfacing rolls according to indicators that determine their structural characteristics.

Study of the influence of external actions on the strength characteristics of the metal of welds and surfacing beads.

When conducting electric arc processes, the evaluation of the results of metal welding is mainly carried out for different zones: the fusion zone with the base metal and the surrounding weld zone.

Simultaneously solving the problem of increasing strength due to the above-mentioned components is quite a difficult task. There is quite a large number of methods and devices that affect obtaining acceptable strength indicators of the product being welded or welded. An enlarged version of the systematization of these methods and devices is presented in Fig. 1.

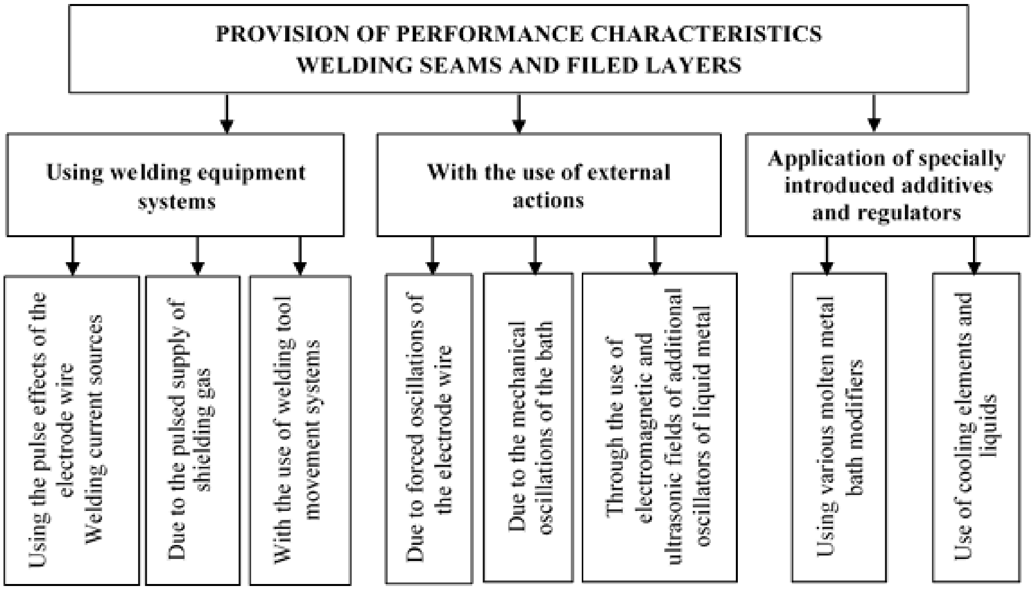


Figure 1. Methods of improving the performance properties of products during welding-surfacing

This systematization structure reflects only the main methods of increasing the strength of products in the welding zone.

Let us consider in more detail the main positions of ensuring the operational characteristics of welded joints and welded rollers, which correspond to the proposed option of systematization (Fig. 1). Some of the methods shown in Fig. 1 were already considered in our research [2]. In this material, more attention will be paid to issues related to the strength problems of welded joints and welded rolls, determined by their structural characteristics.

The systems that form the basis of welding equipment are one of the most effective and cheapest means of solving the problems of structuring the weld metal. During this, sometimes it is not necessary to create new technical solutions, but only change the algorithm of their functioning at the expense of fairly simple control devices. This almost entirely applies to systems implementing welding current modulation processes due to the pulsed supply of the electrode wire and welding voltage using the welding current source [3]. Synchronous change of current and voltage can be the most effective. The modulation frequency cannot exceed 5 Hz, as this is due to the electromechanical properties of electric motors, which are usually used in the electrode wire feeding systems of welding and surfacing machines and serially manufactured devices. Special electric motors are required for higher modulation frequencies. When using modulation, a number of effects can be achieved, including those related to solving strength problems. More important for the quality of mechanical characteristics are inclusions that may be in the weld. Experimental comparative studies show that non-metallic and gas inclusions most significantly effect the strength. Reducing their content allows to improve the operational characteristics of the welded joint and surfaced layers. This is primarily substructural strengthening with the reduction of non-metallic and gas inclusions. The effectiveness of this influence is shown in Table 1, where, based on the analysis of cross-sections, a comparative average estimate of non-metallic and gas inclusions in the weld metal during flux-cored welding is made.

Table 1

Non-metallic and gas inclusions in metal weld bead

Non-metal and gas inclusions in metal weld bead	Turn on the volume part, %	Part of the gas turn on, %
Stationary mode	0,75	0,129
Mode with parameter modulation	0,65	0,097

Subsequently, the share of non-metallic and gas inclusions can be reduced to 25%, which naturally increases the characteristics of the welded joint.

The most important effect that can be achieved using modulated modes of operation is the creation and use of polycrystalline effects based on the grinding of grain sizes and the general change in the structure of the entire composition of grains and their boundaries. Here we can talk about some disorientation of grains – crystallites. Fig. 2 presents the sizes of crystallites in various zones in metal weld bead, while the following modes were applied: a) without modulation; b) and c) with mode modulation at frequencies of 1.1 Hz and 2.5 Hz, respectively.

It should be noted that different methods of welding – surfacing with modulating modes give different results of changing crystal sizes. So, for example, welding under a flux at high modes with modulation of the welding current provides only the order of crystallite sizes that is characteristic of the original sample.

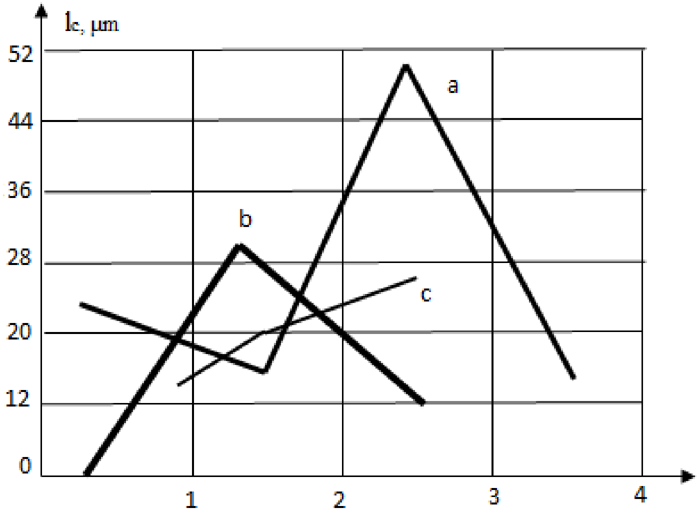


Figure 2. Width of crystallites: 1 – weld root µ; 2 – middle of the weld; 3 – weld top

In this case, all this, in our opinion, is due to the thermophysical characteristics of the corresponding electric arc process using an electrode wire. In the case of the general use of modulated modes of operation, the impact on the metal structure of the welded joint is exerted by electrodynamic actions. Impulse effects in the transient modes of operation of the modulator are one of the most important factors of pressure on the welding pool with its mixing, which creates the conditions for the release of non-metallic and gaseous inclusions, as well as the crushing of crystallites. Reducing the size of crystallites, as defined in [4] and other studies, increases the strength characteristics of the joint. Some results of comparative studies in the surfacing of alloy steel with electrode powder self-shielding wires are presented in Table 2, while the corresponding measurements were carried out on a large number of samples, and then the results were averaged.

Table 2

Results of study of mechanical properties

Mechanical properties of samples in the center of the weld				
Method of welding	Mechanical properties (average value)			
	Yield limit kgf/mm	Temporary resistance to rupture	Relative elongation %	Impact viscosity J/cm^2 at the temperature of 20^{0}C
Stationary arc	308	461	28,3	100
Modulated mode	316	472	28,9	126

The improvement of the mechanical properties of surfacing when using modulated processes is noticeable. A particularly perceivable is the increase in the value of viscosity, which is mainly determined by the size of the crystallites, as well as the value of the yield strength.

The Hall-Petch equation can be used to estimate the value of the yield strength of a metallic material [5]

$$\sigma_\tau = \sigma_0 + \frac{K}{\sqrt{d}}, \qquad (1)$$

where σ_o and K are special coefficients; d is the grain size (crystallite).

The coefficients σ_o and K are rather difficult to determine, but as stated in [6], they can be theoretically and experimentally established for a number of conditions. It is also important in equation (1) that the plasticity of the weld metal has a certain dependence on the size, where with the decrease of this size, the flow rate increases, as an integral element of the strength of the product. When the electrode wire is pulsed, the effects of its influence are even more obvious and more significant for ensuring the strength characteristics of the product. In this, the controlled transfer of the electrode metal plays a special role.

The method of welding-surfacing with pulsed supply of electrode wire has existed for a long time in various versions [7], but its application was held back by the complexity of adjusting the main parameters, as well as the insufficient reliability of mechanical converters of the rotary motion of the drive electric motor shaft into linear-impulse motion of the electrode wire. These are mechanisms with one-sided grippers and mechanisms with quasi-wave converters – QWC. At present, the development of a pulse supply mechanism based on a valve electric drive with a regulator based on programmable controls has been completed. Such a mechanism implements almost any algorithm of pulse feeding of the electrode wire with the setting of the frequency f , spacing S, size and shape of the pulse with the frequency of the undistorted pulse can be 50...60 Hz. Feedback of the parameters of the arc process can be entered into the controller of the electric drive. The introduction of feedback on the welding current makes it possible to implement the welding-surfacing technology presented in [8] – this is a process with metered supply of the electrode wire. The study of pulse feeding using a new feeding mechanism included, in particular, the study of the structure and microstructure of the metal.

It can be noted that prolonged overheating of the metal at high temperatures contributes to the increase in the size of the crystallites. This is inherent in the zone of overheating of the weld metal. Therefore, the measurement of the grain score in this zone is a criterion for the entire cross section.

Table 3 shows the metal grain score in the area of overheating, performed within the scope of the research presented in the paper [9].

Table 3

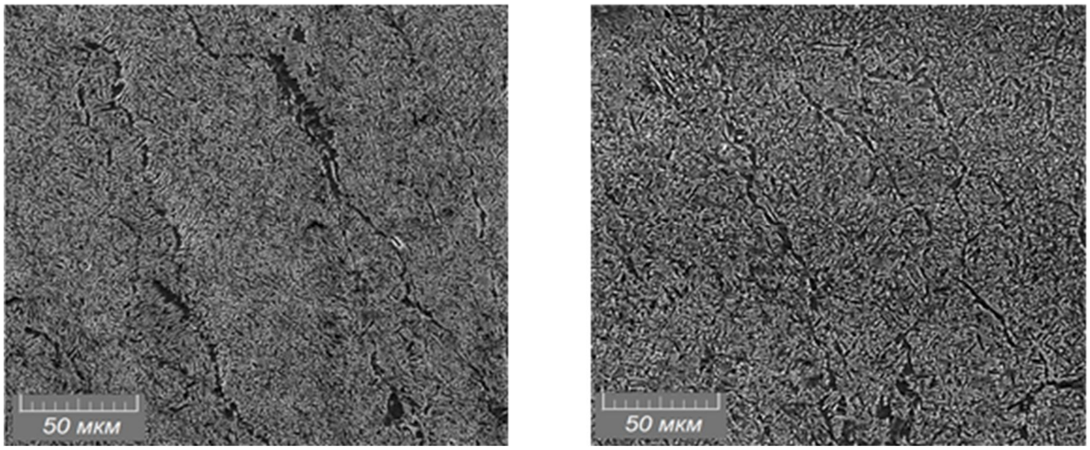
The results of grain score studies in the area of overheating

№	1	2	3	4	5	6	7	8	9	10	11	12	13
f	0	10	30	50	10	30	50	10	30	50	10	30	50
S	1	5	5	5	3	3	3	2	2	2	1,25	1,25	1,25
grain score	6–7	8	7–8	7–8	7–8	7	6–7	6–7	6–7	6–7	6–7	6–7	6–7

Analysis of Table 3 shows that the grain score increases with an increase in the sparability, which, in our opinion, is due, among other factors, to an increase in the action of the electrodynamic force, and therefore, to the intense oscillation of the liquid metal pool due to a more «sharp» pulse. This contributes to both grain crushing and reduction of the content of non-metallic inclusions and gases.

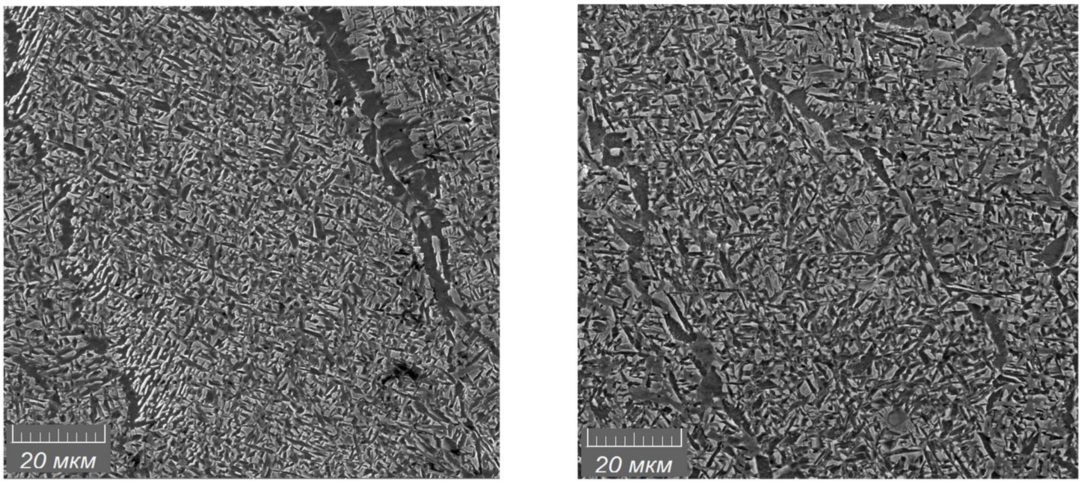
Fig. 3 and Fig. 4 show comparative photographs of microsands of cross-sections of welds in large magnifications of various magnifications.

Metallographic analysis of surfaced metal at a higher magnification (×1000...2000) in the photos in Fig. 3 and Fig. 4 showed that a more favourable shape of the boundaries of the crystallites is observed from the pulsed supply of the electrode wire. It was also noted that the thickness of the layers of polygonal ferrite, which is considered the most dangerous structure from the point of view of brittle fracture, decreases by 1.5...2 times.



a) b)

Figure 3. Microstructure of deposited metal 30KhGSA, electron microscopy data ×1000:
a – at normal feed; b – pulse feed



a) b)

Figure 4. Microstructure of deposited metal 30ХГСА, electron microscopy data ×2000:
a – at normal feed; b – with pulse feed

As mentioned, the overheated area of the weld is the center of crystallite growth and, therefore, the most interesting for research. Table 3 presents the results of the evaluation of the grain score in the area of overheating, and Table 4 shows the results of the research on determining the size of weld crystals. It can be considered that the reduction of inclusions in the weld metal and the crushing of its structure are the main effects that depend on the influence of mechanical systems of welding equipment that are purposefully used to solve these problems. These effects, as noted, are reached is mainly due to the electrodynamic effects in the pool when pulsed influences are applied.

Table 4

Quantitative indicators of the shape of crystallites in the deposited metal

Method of surfacing in CO_2 with feed	Crystallite width, μm	Coeff. forms of crystallites
ordinary	97,5	6,8
pulse	70,0	4,56

The tribological characteristics of the deposited layer are an important indicator, in particular, for the surfacing of nodes and parts operating in friction zones. These characteristics can be evaluated by the loss of mass after a certain time of operation, or the total length of the travelled path. The results of such a study in a comparative form for several samples with determination of the average value (rate) of wear are presented in Table 5.

Table 5

Wear rate

No	Frequency *f*, Hz	Sparseness *S*	number of layers	Average wear rate, mm^3/km
1	Initial Sample		1	7,3
2	15	3	1	3,8
3	60	3	1	6,6
4	20	5	1	4,2
5	60	5	1	5,8
6	Initial Sample		5	3,9
7	15	3	5	3,2
8	60	3	5	3,4
9	20	5	5	2,7
10	60	5	5	3,3

The study of other important mechanical operational properties of the deposited metal in a comparative form of parameters is presented in Table 6 and 7. Herewith, an important parameter of the pulsed supply of the electrode wire is calculated – the acceleration in the pulsed movement, the value of which has a significant effect on the electrodynamic pressure on the liquid metal pool, and therefore on the properties of the deposited bead. This parameter is also given in Table 6.

Table 6

Welding modes and pulse feed parameters

No	Feed	Feed rate, m/h	Step mm	Frequency, Hz	Acceleration, m/s^2	Current, A	Voltage, V
1	Slow	190…200	-	-	-	160…170	23…24
2	Slow	220…230	-	-	-	190…200	25…26
3	Pulse	190…200	2,0	28	40…50	160…170	23…24
4	Pulse	190…200	3,0	18,5	60…70	160…170	23…24
5	Pulse	220…230	2,0	32	75…80	190…200	25…26
6	Pulse	220…230	3,0	21	90…100	190…200	25…26

It is important to note that the results of the study of the mechanical properties of welds and beads correlate quite well with the acceleration of the electrode wire in the feed pulse and this can be explained from the point of view of force effects on the molten pool. As the acceleration value increases, all indicators of the mechanical properties of the welded joint increase.

A detailed analysis of the weld microstructures shows that at an acceleration of 90...100 m/s² dendrites are practically absent, the average austenite grain size decreases by 1.5...2.5 times compared to conventional welding.

Consideration of the impact of pulsed supply of protective gas on the structure of weld metal (WM) is less relevant for several reasons. First of all, welding and surfacing processes in the environment of protective gases are not applicable everywhere, as well as their poor controllability with the gas flow due to the inertial nature of gas movement and systems for controlling this movement. There are well-known studies of this process, for example, [10] and other researches, where the advantages of impulse supply of shielding gas are determined, in particular, when using gas supply in a variable way [11], with periodic changes in gas pressure, etc. It can be noted that the control of the shielding gas supply affects both the transfer of the electrode metal and the pressure on the liquid metal pool, as well as the periodic forced cooling of the pool metal. This set of influences contributes, in particular, to the structuring of the welded joint.

Table 7

Mechanical properties of metal of welded joints

	Strength limit $\sigma_{\text{в}}$, MPa			Yield strength σ_{τ}, Pa			Impact viscosity J/cm^2 at the temperature of 20^{0}C $a_{\text{н}}$,		
No	MM	WM	HAZ	MM	WM	HAZ	MM	WM	HAZ
1	448	444	438	265	261	256	100	94	93
2	448	445		265	260		100	105	98
3	448	459		265	271		100	102	100
4	448	460		265	271		100	104	
5	448	462		265	273		100	104	
6	448	465	459	265	276	273	100	108	106

Let us consider the most interesting and rather effective developments aimed at improving the structure of the weld metal in order to increase its strength characteristics and based on the application of additional systems in the welding equipment, mainly automatic machines. These are primarily well-known mechanical oscillators of the welding tool – the electrode wire. Such systems with an analysis of the results of their work are described in detail, for example, in [12]. They make low-frequency (up to several Hz) oscillations across the welding direction. Usually, their amplitude is small to avoid significant destructive vibrations. These systems are used to simultaneously solve several tasks at once – expanding the width of welding-surfacing and improving the quality of the weld and the deposited layer.

Among the disadvantages of electric arc welding-surfacing, in particular under flux, is excessive heat investment in the product, since a significantly greater amount of heat is generated in the arc than is perceived by the electrode wire and the processed material. The result of this redundancy is grain growth, which affects the strength characteristics of welds and deposited layers. This phenomenon can be avoided by a relatively new method of welding-surfacing with transverse oscillations of the welding tool – the electrode wire [13] under the direct influence of a mechanical vibrator on the wire, which allows to oscillate the section of the wire close to its melting with adjustable frequency and amplitude. This method makes it possible to concentrate the heat input and thereby reduce the heat load to a certain extent.

The oscillator can be of several types: with a drive electric motor to an eccentric mechanism; with an electromagnetic pusher, etc. In the photo in Fig. 5 a machine for surfacing under a flux using an oscillator of an electrode wire is shown.

Figure 5. Automatic surfacing machine: 1 – feed mechanism; 2 – movement mechanism; 3 – electrode wire oscillator.

It should be noted that when conducting the arc process, oscillation frequencies of the order of tens or even hundreds of Hz are used, while the electrode metal drops are crushed. The sizes of the drops separated as a result of the destruction of the molten metal layer on the end of the electrode wire are determined by the action of two force mechanisms: the integral force balance mechanism and gravity-capillary atomization. The fine droplet transfer of metal ensures a higher efficiency of heat transfer from the arc to the electrode. Subsequently, the efficiency of surfacing significantly grows, in particular, the productivity increases. When applying a new method of welding-surfacing, it is important to form the structure of the metal, which can improve the strength characteristics. The results of the study of the hardness of the welded bead in its various zones are presented in Fig. 6.

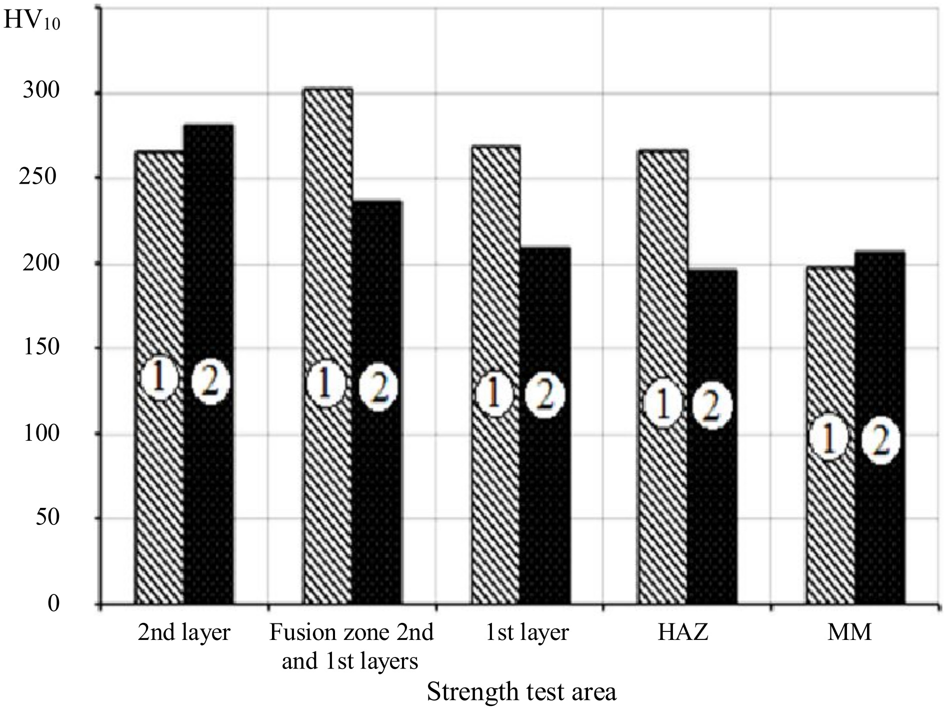


Figure 6. Measurement of hardness of the deposited bead in various zones of its cross-section: 1 – surfacing using electrode vibration; 2 – surfacing without vibration.

Analysis of the graphs shows a significant increase in hardness in the most problematic areas. Measurements of the hardness of the deposited layer showed (Fig. 6) that as a result of the decrease in the proportion of the main metal (OM, MM-main metal) in the first pass, the hardness of the deposited metal increases by 50 HV_{10} compared to the deposition performed without vibrations, reaching 300 HV_{10}. When depositing using standard technology, such hardness is achieved only in the second layer.

Let us consider another method that allows to improve a significant number of characteristics of the deposited bead, which is also carried out by an additional mechanism – the oscillator of the product that is deposited or welded, and therefore, the pool of liquid metal [14]. Fig. 7 shows the schematic design of the oscillator of the pooltub product.

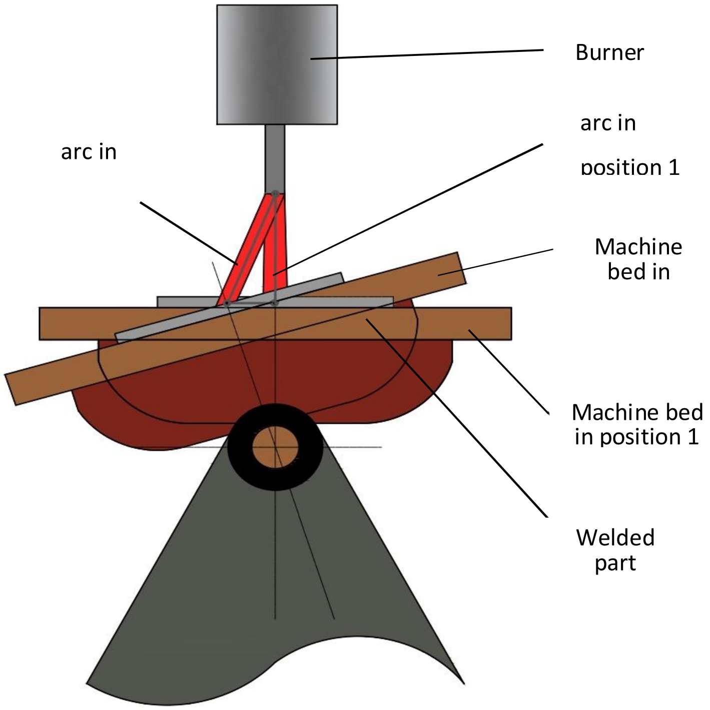


Figure 7. Scheme of oscillations of the arc length during oscillations of the weld pool: 1 – position in the absence of oscillations; 2 – position during oscillations of the machine bed (weld pool)

Oscillations of the product are carried out in a plane perpendicular to the direction of welding-surfacing with a special gearless electric drive using a stepper electric motor controlled by certain algorithms.

The step electric drive and design features of the oscillator allow to adjust the frequency and amplitude of oscillations of the product and the pool within wide range, which makes it possible to choose, taking into account the parameters of the arc process, the most effective mode of operation to obtain the required result.

In this process, there is quite effective mixing of the pool of molten metal, as well as dynamic effects on the pool caused by periodic changes in the overhang of the electrode wire. All this leads to a decrease in non-metallic inclusions in the welded beads, as well as to a decrease in the growth of crystallites due to a constant change in the position of the arc. At the same time, the heat load on the electrode material and the material of the welding pool of the deposited bead is reduced.

The cycle of studies of the influence of changed structure of the deposited metal when applying the method with controlled oscillations of the liquid pool is presented in Table 8 with a fairly large number of hardness determination results over the entire field of the cross-section of the deposited bead. This study also presents a wide range of influences with various parameters, which allows to form the determining factors of the influence of the considered surfacing method on one of the most important factors of the strength of the surfacing layer – hardness, which confirms the conclusions of other researchers, for example, [15].

Table 8

Hardness values of weld metal and HAZ metal

No	Surfacing current I_{sc}; A	Welding rate V_{ws}; m/h	Oscillation frequency υ; Hz	Oscillation amplitude; A; mm	Vickers hardness of surfacing metal (load 1 kg), x10^7 Pa			Vickers hardness HAZ (load 1 kg), x10^7 Pa		
					Weld top	Weld center	Weld root	Weld top	Weld center	Weld root
1	100	10	4	7	195	193	187	217	224	208
2	100	14	3,5	6	199	203	203	212	203	224
3	100	18	4,5	3	217	226	223	254	261	266
4	100	22	2,5	4	223	223	233	233	229	229
5	100	26	3	5	221	201	210	217	214	221
6	125	10	3,5	3	205	199	217	208	207	208
7	125	14	3	7	218	219	222	210	218	214
8	125	18	4	4	222	224	232	250	245	248
9	125	22	4,5	5	250	232	229	270	275	272
10	125	26	2,5	6	260	279	271	320	313	317
11	150	10	4,5	6	214	214	224	202	205	205
12	150	14	4	5	229	229	229	245	243	245
13	150	18	2,5	7	214	210	210	197	193	195
14	150	22	3	3	222	217	232	258	260	264
15	150	26	3,5	4	251	257	251	283	287	287
16	175	10	3	4	208	207	203	220	222	225
17	175	14	2,5	3	202	173	178	173	178	175
18	175	18	3,5	5	208	214	224	228	228	230
19	175	22	4	6	222	219	238	227	232	229
20	175	26	4,5	7	208	219	212	229	228	229
21	200	10	2,5	5	193	193	192	200	198	203
22	200	14	4,5	4	219	225	229	225	229	229
23	200	18	3	6	217	226	218	213	215	214
24	200	22	3,5	7	216	214	210	217	218	219
25	200	26	4	3,5	203	205	179	215	215	213

It can be noted again that the heat-affected zone (HAZ) refers to problem areas with large grains and a high degree of chemical heterogeneity, which can significantly affect the characteristics. This is allocated to a separate block of research and presented, also in Table 8. The obtained results of detailed studies allow to build mathematical and graphical models of the influence of the deposition mode parameters with pool oscillations, which in turn facilitates the selection of equipment operation modes to solve the task of improving the quality of the deposited layer. The study was tested with a highly positive result in the regenerative dopositing of dies of a stamping tool weighing about 10...15 kg.

Recently, there have been developments to improve the structure of the weld metal using original technical solutions based on mechanical vibrators. One of the variants of such a vibrator is presented in Fig. 8 a) [16].

The device for welding pool vibrations includes: 1 – body; 3 – rod; 6 – drive; 7 – faceplate; 8 - rod attachment (used tungsten electrode of the device for argon arc welding with a non-melting electrode). Additionally, on the structure diagram in Fig. 8 there are: 2 – electric current supply; 4 – pool of molten metal; 5 – arc space. l_n – the distance from the end of the rod to the axis of the electrode, h- the depth of immersion of the rod; $V_{зв}$ (V_{ω}) – feed rate; I, II, III – directions of movement. All parameters, e, l_n , h, are adjustable, as well as the rotation rate of the drive electric motor shaft. The amplitude of oscillations is determined by the amount of eccentricity e, and the frequency depends on the rotation rate of the drive electric motor shaft. Comparative microstructures in Fig. 8 b), c) were made at a vibration frequency of 40 Hz with an amplitude of 0.5 mm.

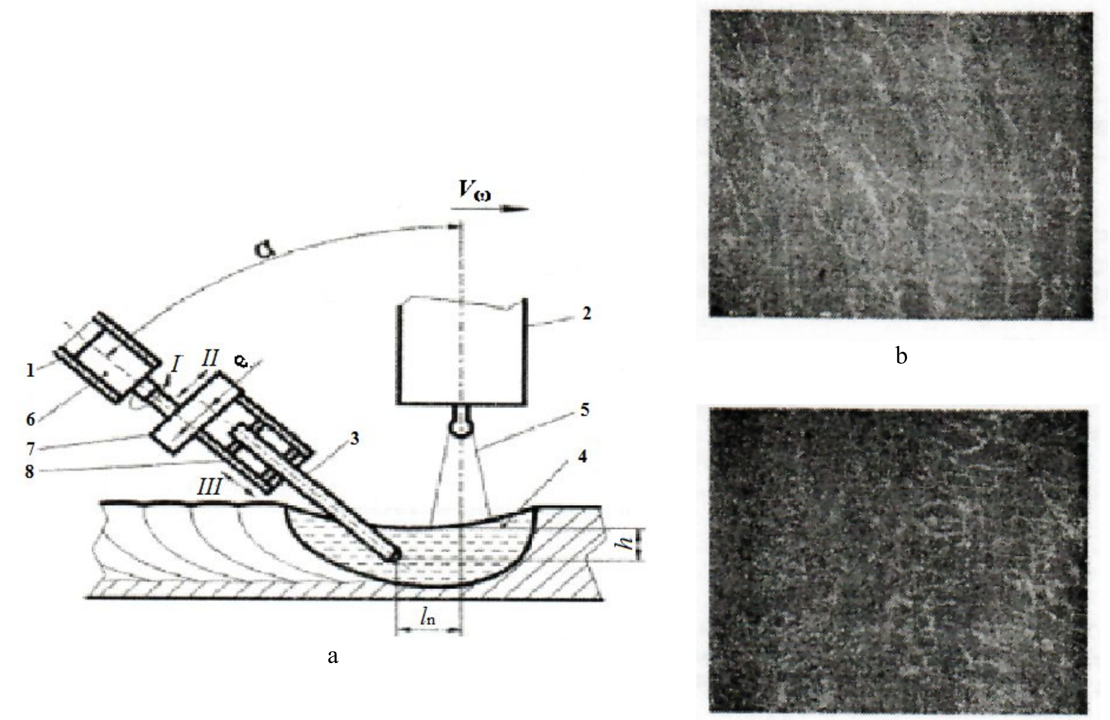


Figure 8. a – structure of the pool vibration mechanism;
b, c – weld metal microstructures without vibrations and with vibrations, respectively

From the analysis of the structure of the microslides, it follows that the mechanical vibration of the melt in this technical solution allows to significantly reduce the size of the crystallites, as well as to disorient them. All this helps to increase the strength characteristics of the weld metal, and due to the sufficient ease of use, this technical solution – a kind of welding shaker – can be used in almost all automated welding and surfacing processes.

It is important to point out that a serious impact on the structure of the metal of the weld and the deposited layer is exerted by electromagnetic influences, which are specially introduced to improve the quality of the metal, contributing to the activation of the movement of liquid metal of the pool, organization of transfer of the electrode metal with all the resulting effects [17]. It should be noted that the use of electromagnetic fields gives good results in improving almost all characteristics of welding and surfacing, however, unlike the previously discussed systems and methods, it is rather difficult to implement.

It can be emphasized on the possibility of applying other methods of influence on the structure of the weld metal, for example, the use of ultrasonic influences which are described in a number of sources, for example [18].

Special attention should be paid to the combined methods and systems used to improve the characteristics of welds and welded beads. Examples of such technical and technological solutions include:

- pulse algorithm of synchronous operation of the welding current source and pulse supply of shielding gas [19];
- pulse algorithm of the welding current source and pulse feed of the electrode wire [20];
- simultaneous use of the pulse mode of operation of electrode wire feeding mechanism and modulation [21].
- There are other proposals, for example [22], concerning the combined application of various influences, which have a different physical nature and make it possible to significantly increase the impact on improving the structure of the weld metal or the deposited layer.

Conclusions. During electric arc welding or surfacing process with a melting electrode, in order to obtain a weld or a welded bead with improved operational characteristics, it is necessary to exert an active influence on their metal structure, which can be achieved by using both welding and surfacing equipment systems and additional systems. Practically all considered methods of improvement either have already been used in industry or can be applied during additional research, taking into account the conditions and specification of parameters of technical and technological suggestions. Herewith, it is important to note that all proposals have real design developments and technological application experience with recommendations. All purposeful effects of the equipment proper systems or additionally introduced mechanical units and parts affect either the control of transfer of the electrode metal or provide such a movement of the metal of the pool that affects the structure of the metal (crystallites size reduction and their disorientation), its degassing and removal of non-metallic inclusions as due to electrodynamic and mechanical forces.

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ВПЛИВ ТЕХНІКО-ТЕХНОЛОГІЧНИХ ДІЙ НА КРИСТАЛІЗАЦІЮ МЕТАЛУ ПРИ АВТОМАТИЧНОМУ І МЕХАНІЗОВАНОМУ ЕЛЕКТРОДУГОВОМУ ЗВАРЮВАННІ-НАПЛАВЛЕННІ

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Резюме. *Наведено узагальнену систематизацію основних напрямів поліпшення структури металу зварних швів та наплавлюваного (шари) металу при електродуговому зварюванні електродом, що плавиться. Зроблено висновок про те, що забезпечення поліпшення властивостей таких структур металу, без втрати своїх основних властивостей, може бути здійснено типовими системами зварювально-наплавного обладнання з наявними в їх конструкції додатковими засобами та за рахунок спеціально розроблених способів їх використання. Визначено, що існує досить широкий ряд конструкцій таких додаткових засобів та способів їх застосування, що спеціально вводяться до складу зварювально-наплавного обладнання. Переважно для запропонованої систематизації розглянуто системи та засоби* *на основі мехатронних та механічних конструкцій. Показано, що використання зварювально-наплавного обладнання, яке містить основні системи забезпечення зварювального процесу, за рахунок застосування в ньому додаткових конструктивних рішень імпульсного руху може позитивно вплинути на структуру металу шва і тим самим поліпшити його механічні властивості. Вказано, що поліпшення механічних (експлуатаційних) властивостей зварного з'єднання або наплавленого шару можна забезпечити введенням нових вузлів і деталей, які можуть забезпечити дегазацію рідкої ванни, зниження в ній неметалічних включень, а також, що особливо важливо, – впливати на ступінь зростання кристалітів, знижуючи його та сприяючи дезорієнтації. На підставі аналізу макро та мікро-шліфів, а також інших даних, представлених у вигляді таблиць та графічних матеріалів, що отримані в результаті проведених експериментальних досліджень, з цілеспрямованого впливу на метал зварювальної ванни різними системами та пристроями зварювально-наплавного обладнання, підтверджено ефективність такого впливу.*

Ключові слова: *систематизація, електродугове зварювання, електрод, що плавиться, наплавлення, кристалізація, імпульсний рух.*

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