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Study of the influence of nanostructured powders on the character of the transfer of electrode metal and the structure formation process of surfaced metal

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Abstract

The paper considers the influence of nanostructured powder-modifiers on the nature of the transfer of electrode metal and the process of structure formation of the deposited metal during surfacing with a consumable electrode in argon. It was found that the more short circuits and less energy is required to ionize the gas mixture in the arc plasma, the more stable the surfacing process. From this position, the most stable is the surfacing process with the use of AlO(OH) nanopowder (10 short circuits per sec.). It was revealed that the sizes of metal droplets change with the introduction of nanopowder, acquiring a more elongated shape, which contributes to a better transition of the metal into the weld pool, thereby reducing spatter. It has been established that when the deposited metal is modified with ultra-dispersed powders, the size of the dendrites decreases in comparison with the deposition without modifiers. A more equilibrium structure in terms of the size of the dendrite is achieved using ultrafine AlO(OH) powder.

Keywords: Transfer of electrode metal; Nanostructured powders; Microstructure of deposited metal

1. Introduction

Today, fusion welding is one of the key technologies in all industries. At the same time, the quality indicators of welded joints and weld deposited surfaces depend not only on the technical capabilities of the mechanical part of the equipment used, but also on the flexibility of the technological process being implemented - the ability to maintain constant or periodically changing electrical and thermal characteristics at the level of instantaneous values[1]. The relevance of solving this problem is constantly increasing, since technical progress makes ever higher demands on the quality of welded structures and the efficiency of welding production.

The transfer of metal from the electrode to the workpiece is one of the most important characteristics of the consumable electrode welding process in shielded inert gases (MIG), it determines the technological characteristics and areas of application of welding processes [2].

There are known works devoted to the transfer of electrode metal during mechanized welding and surfacing with wire [3-6] and strip [7,8] electrodes, in which the relationship between the parameters of droplet transfer and the operational properties of the welded joint is established.

Traditional MIG welding provides fairly good formation and quality of welds but has low productivity due to the small depth of metal penetration. An innovative direction for increasing productivity and increasing the penetration depth is the development of technologies based on the use of nanostructured materials [9, 10].

Purpose of the study: to establish the effect of the nanostructured powder introduced into the surfacing zone on the geometric parameters of the molten metal drop and on the microstructure of the deposited metal.

2. Research methodology

To carry out the research, surfacing by MIG welding of samples made of steel C0.12Cr18Ni10Ti was carried out in an argon atmosphere with a wire C0.12Cr18Ni9Ti with a diameter of 1.2 mm. Samples were deposited in four different ways:

1) surfacing in argon with a solid wire;

2) surfacing in argon with a solid wire with the addition of nanostructured tungsten powder (W);

3)ьsurfacing in argon with a solid wire with the addition of nanostructured powder of aluminum oxyhydroxide (AlO(OH));

4) surfacing in argon with a solid wire with the addition of nanostructured molybdenum powder (Mo).

The concentration of the nanostructured powder in the protective gas is the same in all three cases. The introduction of nanopowders into the weld pool was carried out through the developed device [11]. The device is designed to produce a mixture of argon with nanopowder. It regulates the concentration of nanopowder particles in the volume of protective gas supplied to the arc burning zone. The mixture is formed in the device by injecting the nanopowder with a protective gas. Surfacing modes: welding current Iw = 240-260 A, arc voltage Ua = 28-30 V.

To study and study the influence of the nature of the transfer of electrode metal during surfacing with a solid wire in argon, an experimental complex was designed, shown in Figure 1.

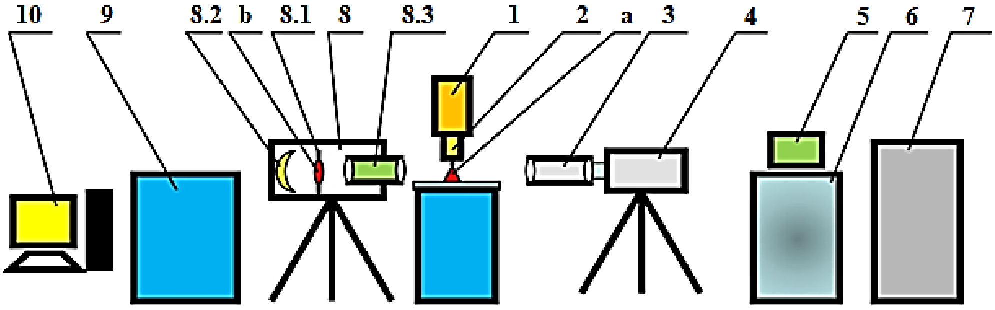

Figure 1. The scheme of the experimental complex: 1 - welding unit for automatic welding with a consumable electrode in shielding gases; 2 - the developed device [11]; 3 - lens system for focusing a digital high-speed video camera on the research object; 4- digital high-speed video camera "Video Sprint"; 5 - digital oscilloscope "DSO 1012A"; 6 - Lorch S8 SpeedPulse power supply for powering the welding arc; 7 - "Mecome" block for automatic control of surfacing parameters (current, voltage, welding speed), arc excitation and extinction; 8 - spotlight to create a "shadow" effect, including: 8.1 - carbon electrodes to create a powerful light source; 8.2 - spherical mirror for reflecting the light flux; 8.3 - lens system for focusing the luminous flux on the welding arc; 9 - power supply TIR-315 for the excitation and supply of the arc between the carbon electrodes; 10 - personal computer.

2.1. Experimental complex operation

Before starting the complex, preliminary focusing of the searchlight (Figure 1, position 8) on the welding arc was carried out, as well as focusing of the digital video camera (position 4) using a lens system (position 3).

The complex was launched in the following order:

1) Starting the power sources of the welding arc (position. 6) and an additional light source (position 9) in idle mode, turning on the automatic welding control unit (position 7), digital recorder of parameters (position 5), computer (position 10) and digital camera (item 4) in standby mode;

2) Adjustment of the required welding mode ("Mecome", position 7) and video recording parameters (using special software installed on the PC, position 10);

3) Excitation of the welding arc (position a) and an additional arc between the carbon electrodes (position b);

4) Registration of welding process parameters (device pos. 5) and video recording (camera position 4);

5) Stopping the supply of energy to the welding arc and additional arc, processing the video image on a PC (item 10);

6) Saving the processed video image file, changing the welding mode parameters, repeating the process from 2 to 6 points.

2.2. Processing of research results

Video processing was carried out using special software. A "storyboard" of video files was carried out with the establishment of the behavior of the system under study at a given moment in time. Data processing of the "DSO 1012A" oscilloscope was carried out using special software.

To determine the volume, the stage was considered at which the drop had already formed, i.e., immediately before the transition to the liquid bath. Obtaining experimental parameters of the geometric parameters of a drop in several stages. The first stage consisted of video filming of the electrode metal droplet transfer process. At the second stage, the video filming was storyboard and digitized, as well as the selection of a frame of the surfacing process, in which the drop is in the last stage before going into the liquid bath. After that, this frame was converted into a raster image. The resulting image of a drop (according to the method [12]) was measured in decimal planes along the X and Y axes, which is sufficient for constructing an adequate model. Based on the numerical values of the "Compass 3D" production process of the company "Ascon" with the subsequent calculation of the geometric parameters (volume) of the intermediaries of the built-in calculation algorithm.

In each sample for the study of the microstructure, transverse slots were made. In the manufacture of the grinding machine, mechanical grinding, mechanical polishing with ASM 10/7 NVL diamond paste and chemical etching in concentrated aqua regia (75% HCl + 25% HNO_3) were used. The study was carried out by optical metallographic on a Neophot-21 microscope with image recording using a Genius VileaCam digital camera.

3. Results and discussion

Analysis of the oscillograms of the current in the welding circuit and the voltage between the electrode and the workpiece showed that the process proceeds stably and in all cases with short circuits of the arc gap. However, the frequency of short circuits in the arc gap during welding with and without nanopowder is different. The highest frequency of short circuits is observed when welding with the addition of AlO(OH) (10 s.c./sec) (Figure 2, c).

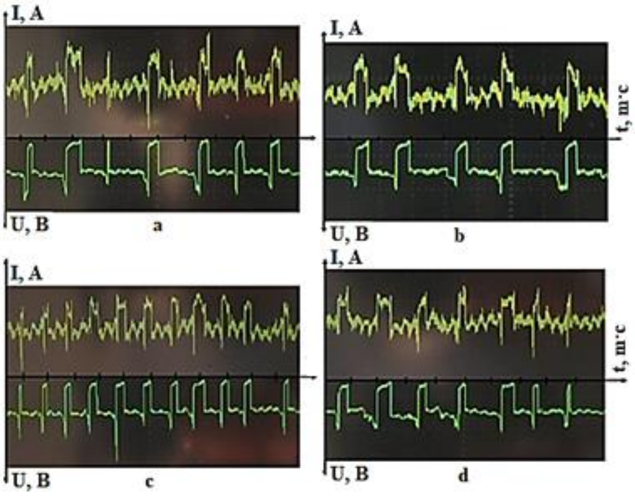

Figure 2. Oscillograms of the current in the welding circuit and the voltage between the electrode and the workpiece of the surfacing process in argon with a solid wire: a - without the use of nanopowders; b - with the addition of W; c - with the addition of AlO(OH); d - with the addition of Mo

In the process of surfacing without the addition of nanopowder and with the addition of Mo nanopowder, the frequency of short circuits was 7 s.c./sec (Figure 2, a, d). The smallest number of short circuits (5 s.c./sec) (Figure 2, b) was observed during surfacing with the use of W.

The difference in the frequency of short circuits can be explained by the fact that in all four cases the composition of the arc plasma was different, i.e., it burned not in a homogeneous gas, but in a mixture of gases and vapors of different metals. In addition to argon and metal vapors that make up stainless steel, tungsten is present in the arc gap in the second case, aluminum oxyhydroxide in the third, and molybdenum in the fourth. For aluminum, the energy of a single ionization is 25% lower than that of iron (in this case, it was taken as a comparison, since its amount is maximum in the arc zone), and for iron, the energy of a single ionization is only 2% less than that of tungsten and molybdenum. Also, it should be noted that aluminum has the lowest electron work function (3.5% less than iron), and iron is 1% lower than tungsten and molybdenum.

The concept of "arc stability", the physical meaning of which was most fully formulated by Yu.N. Lankin in the article [2] made it possible to establish that the most stable welding process using AlO(OH). Under these conditions, a greater number of short circuits and less energy were observed to ionize the gas mixture in the arc plasma.

The processed cinegrams of the surfacing process according to the method [12] made it possible to establish the relationship between the geometric parameters of the transferred drops of the electrode metal and the presence of nanopowders in the shielding gas and, accordingly, in the deposited metal. The three-dimensional model and geometric parameters of the obtained drops are presented in Figure 3.

It is known [13, 14] that a decrease in the drop transition time and an increase in the number of short circuits in arc fusion welding confirms that the transfer of the electrode metal is carried out by smaller droplets of the electrode metal. This pattern was observed in the study. It was found that with an increase in the frequency of short circuits, the volume of metal droplets decreases, as well as a change in their shape. The smallest drop volume was obtained at a frequency of 10 s.c./sec, and amounted to 2.7 mm3 (Figure 3, c). The drop with the largest volume equal to 4.9 mm3 was obtained at a frequency of 5 s.c./sec. (Figure 3, d). It was also found that the geometric parameters of the drops were strongly influenced by the nanostructured powder. In its presence, the size of the metal droplets decreased in diameter and increased in length, which helps to reduce metal spatter during arc welding in argon with a solid wire.

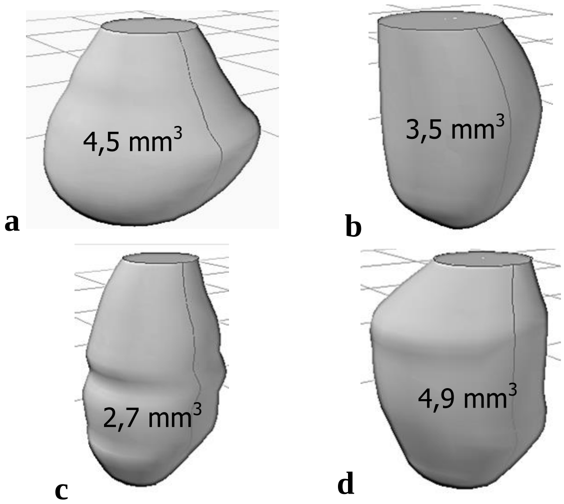

Figure 3. Three-dimensional model and the volume of molten metal droplets without the nanopowder (a), with the addition of nanopowder: W (b), AlO(OH) (c), Mo (d)

Droplet transfer of electrode metal affects metallurgical processes occurring in a liquid weld pool, crystallization processes, formation of a weld and microstructure of the deposited metal. Therefore, the analysis of the microstructure of the deposited metal obtained by this welding method is important.

The investigated nanostructured powders are modifiers and will contribute to a change in the microstructure of the weld metal. Currently, the method of grinding the structural components of the deposited metal is widely used [15-17]. This is achieved by introducing nanodispersed metallic and nonmetallic modifier powders into welding consumables or directly into the weld pool.

Analysis of the structure of the deposited metal showed that it has three layers, the structure and thickness of which are significantly different for different welding conditions. In Figure 4 shows a general diagram of the location of the places for studying the microstructure of the seams.

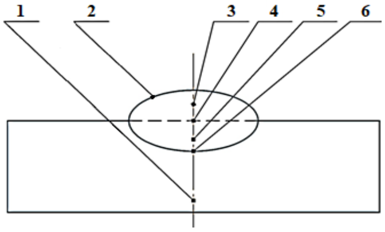

Figure 4. The layout of the places for the study of the microstructure of the weld: 1 - base metal; 2 - welded seam; 3 - top layer of deposited metal; 4 - middle layer of deposited metal; 5 - bottom layer of deposited metal; 6 - section of transition from deposited metal to base metal (fusion boundary and HAZ)

At point 1, the structure of the base metal was recorded; it is the same for all samples. Point 6 corresponds to the structure of the area of transition from the surface layer to the HAZ and further to the base metal (Figure 5 a, b, c, d).

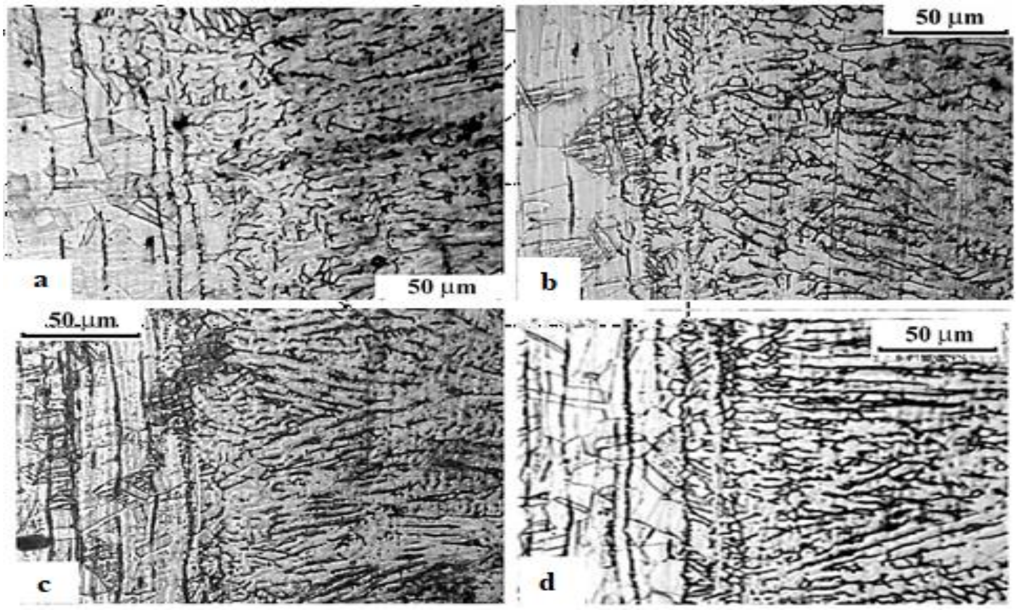

Figure 5. Fusion boundary and heat affected zone structure: a - without powder; b - with the addition of powder W; c - with the addition of AlO(OH) powder; d - with the addition of Mo powder

The HAZ in all samples was clearly identified and had different widths. At the fusion boundary, there was a smooth transition from the dendritic structure of the surface layer to the polyhedral grain structure of the heat-affected zone.

Points 3, 4 and 5 corresponded to the characteristic structures noted above for the layers (Figure 4) of the deposited metal. The first layer (layer 3, Figure 4), immediately adjacent to the free surface, can be characterized as a layer with a polyhedral grain structure (Figure 6).

In layer 3 (Figure 4), along with chaotically located (non-oriented) dendrites, polyhedral austenite grains were observed. This layer was weakly expressed in the sample without modifiers (Figure 6, a). Its thickness is 0.6 mm, which is 15% of the total thickness of the surface layer.

The most pronounced "grained" layer is expressed in the sample modified with ultrafine powder of aluminum oxyhydroxide (Figure 6, c). There are distinct grains of olyhedral morphology, which alternate with islands of short, non-oriented dendrites.

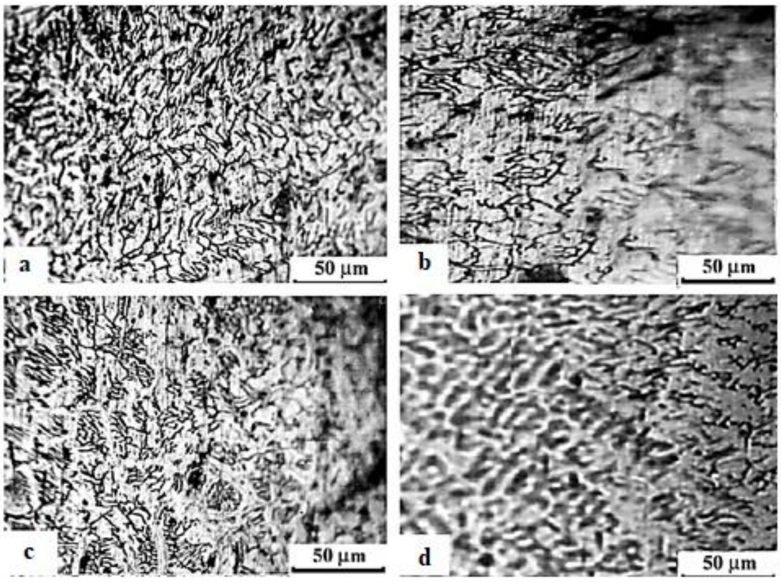

Figure 6. Microstructure of the layer of polyhedral grains; a - without powder; b - with the addition of powder W; c - with the addition of AlO(OH) powder; d - with the addition of Mo powder

The thickness of the considered layer is 1.3 mm, which is more than 30% of the total thickness of the surface layer. In the samples modified with ultradispersed tungsten and molybdenum powders (Figure 6 b, d), the polyhedral grain structure was also observed quite clearly. However, a feature is that the grains contain short and highly branched dendrites. The layer thickness was 0.9 mm or 20% of the total.

The main microstructural component of layer 4 (Figure 4) consisted of relatively short, highly branched dendrites with no preferential orientation (Figure 7).

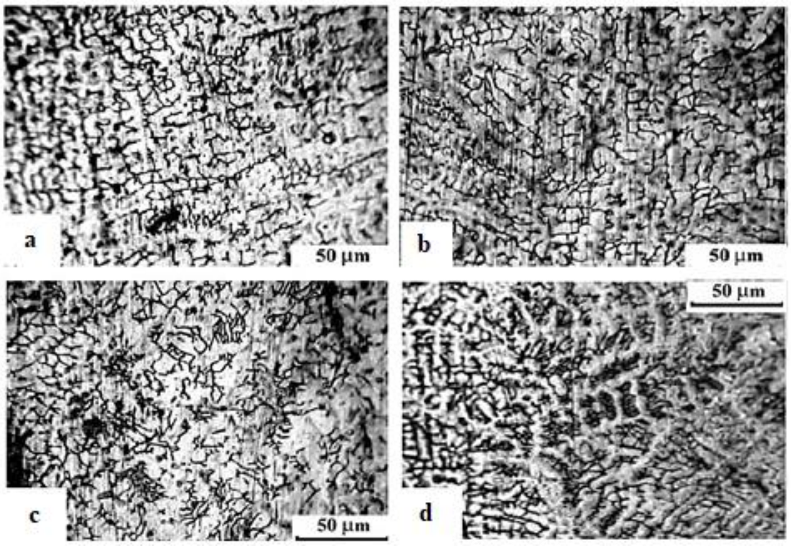

Figure 7. Microstructure of the layer of non-oriented dendrites; a - without powder; b - with the addition of powder W; c - with the addition of AlO(OH) powder; d - with the addition of Mo powder

Layer 4 (Figure 4) was again weakly expressed in the sample without modifiers (Figure 7, a). Its thickness was 1.1 mm (28% of the total). The same value of the thickness of layer 4 was observed in samples modified with ultradispersed tungsten and molybdenum powders (Figure 7 b, d), but in percentage terms it was less than 26%. The layer of non-oriented dendrites was most pronounced in the sample modified with ultradispersed aluminum oxyhydroxide powder (Figure 7, c). At the same time, if in samples 1, 2, and 4 the dendrites formed an almost continuous network, then in sample 3, islands of the free surface were observed, where, at the same time, it was not possible to distinguish grain boundaries. The thickness of the layer of non-oriented dendrites in sample No. 3 is 1.5 mm, which is 32% of the total.

Layer 4 (Figure 4) smoothly passes into the layer (layer 5, Figure 4) of oriented dendrites. The orientation of the long axes of the dendrites in the layer under consideration (Figure 8, a-d) is normal to the fusion boundary - along the direction of the heat flow into the base metal. The layer of oriented dendrites in the sample without modifiers is 2.3 mm, which is 57%, in the sample modified with ultrafine tungsten powder 2 mm or 45%, in the sample modified with ultrafine aluminum oxyhydroxide powder 1.8 mm or 43%, in the sample modified ultrafine molybdenum powder 2 mm and 45% of the total thickness. Immediately before the fusion boundary, the strict orientation of the long axes of the dendrites is again violated, and another thin sublayer of non-oriented dendrites about 20 μm thick is formed.

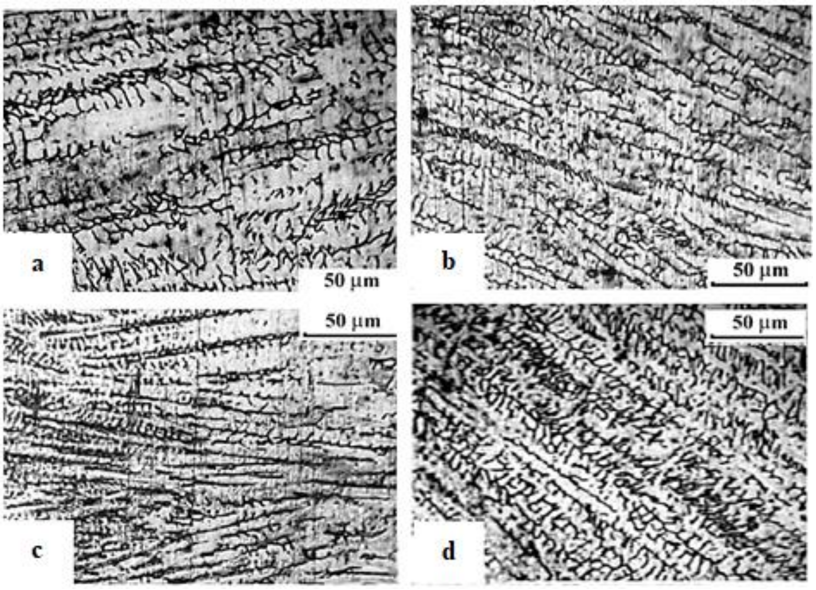

Figure 8. Microstructure of a layer of oriented dendrites: a - without powder; b - with the addition of powder W; c - with the addition of AlO(OH) powder; d - with the addition of Mo powder

The most branched and thickest dendrites were observed in the sample without the modifier. The thinnest and weakly branched dendrites were observed in the sample modified with aluminum oxyhydroxide.

According to generally accepted concepts [16, 17], the less is the dendritic structure of the surface layer and the less rough the structure of dendrites, the better the mechanical properties of the surface layer. From these positions, the sample without modifiers is inferior to the samples modified with ultrafine powders W, Mo, and AlO(OH). The most equilibrium structure in terms of the size of the dendrite is achieved when modified with ultrafine AlO(OH) powder.

4. Conclusion

1. According to the literature review, methods are known for introduction nanostructured powders into the welding zone using special welding materials: flux-cored wire; covered electrodes; welding flux. The proposed method consists in the dosed introduction of nanopowders into the welding zone through the transporting gas during MIG using standard welding wires, which makes it available for widespread use.

2. It has been established that the introduction of nanostructured powders into the welding zone through a shielding gas when surfacing in an argon atmosphere with a solid wire allows: to increase the number of short circuits from 7 short circuits / sec. up to 10 short-circuits / sec, which leads to an increase in the number of drops of electrode metal transferred to the weld pool; to reduce the size of the transferred droplets (the volume of a molten metal droplet without the introduction of nanopowders is 4.5 mm3, and with the introduction of AlO (OH) nanopowder – 2.7 mm3). With the introduction of nanopowders, the droplets acquire a more elongated shape, which contributes to a better transition of the metal into the weld pool, thereby reducing the amount of spatter. When processing the results of experimental studies of the parameters of the droplet transfer of the electrode metal, not only the qualitative and quantitative parameters characterizing the stability of the welding process, but also the volume and shape of the droplets were determined, which made it possible to obtain input data with a high degree of reliability for the development of mathematical models of the distribution of temperature fields over the surface of the welded product and its verification.

3. It was found that when modifying the deposited metal with ultradispersed modifier powders, the dendrite size decreases compared to surfacing without modification in the dendrite thickness by 33% (Mo), W – by 33%, AlO(OH) – by 40%, in width dendrite by 38% (Mo), W – by 48%, AlO(OH) – by 67%. A more equilibrium structure in terms of the size of the dendrite is achieved using ultrafine AlO(OH) powder.

Acknowledgments

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