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EFFECT OF AMPLITUDE AND FREQUENCY OF PLASMATRON OSCILLATIONS ON CHEMICAL AND STRUCTURAL INHOMOGENEITY OF METAL DEPOSITED BY PLASMA-POWDER METHOD

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Effect of amplitude and frequency of plasmatron oscillations on formation of deposited beads, nature of base metal penetration as well as structural and chemical inhomogeneity in zone of joining of deposited and base metals was investigated. The plasmatron oscillation frequency has the largest effect on bead shape and its microstructure, increase of amplitude rises bead width and decreases its height. Effect of plasmatron oscillation frequency on nature of base metal penetration and chemical and structural inhomogeneity in zone of joining of base and deposited metals along surfacing direction was also investigated. In deposition with plasmatron oscillations there is a wavy configuration of interface of deposited and base metals in longitudinal direction with higher frequency of projections and cavities, which repeats plasmatron oscillation frequency. It is determined that increase of plasmatron oscillation frequency on projections as well as cavities in fusion line promotes decrease of deposited and base metals stirring and content of main alloying elements rapidly changes. 6 Ref., 11 Figures.

Keywords: *plasma-powder surfacing, oscillations of plasmatron, amplitude and frequency of oscillations, base metal penetration, chemical and structural inhomogeneity, formation of deposited metal*

It is known that plasma-powder surfacing in the most cases is carried out with plasmatron oscillations. This allows depositing beads of set width and height with minimum penetration of a base metal in one pass [1–6]. An analysis shows that if electric indices of surfacing mode and rate of wire feed are not taken into account than amplitude and frequency of plasmatron oscillations as well as surfacing rate have the main effect on these characteristics of deposited beads. Moreover, all these characteristics are interconnected and at change of one of them and in order to get quality deposited beads it is necessary to adjust two other characteristics.

The aim of the present work was to study an effect of amplitude and frequency of plasmatron oscillations on formation of deposited beads, nature of base metal penetration as well as structural and chemical inhomogeneity in joining zone of deposited and base metals.

Effect of amplitude and frequency of plasmatron oscillations as well as surfacing current on formation of deposited metal beads was studied at the first stage. At that the amplitude was changed in a range of 0–7 mm, frequency — 30–90 min^{-1}, current — 210–270 A. Surfacing rate made 10 m/h, powder feed 3.3 kg/h, filler powder PR-10R6M5. Deposition of single beads was carried out on 15 mm thick plates of steel St3. Investigations of bead shape and their structure were carried on macro- and microsections.

The most significant effect on bead shape and its microstrucutre has a plasmatron oscillation amplitude. Increase of the amplitude rises bead width and reduces its height (Figure 1, *a*), During surfacing without oscillations ($A = 0$) at 240–245 A current the bead is high and has small roll (coefficient of bead shape equals to 1.8), however, in whole formation is good. With 2–3 mm amplitude the formation is good, bead cross-section is of half-round shape with wetting angle not less than 90°. Further increase of oscillation amplitude promotes rise of bead width b and its height h reduces and bead becomes flatter.

Effect of surfacing current on bead shape is regular, i.e. rise of current makes bead lower and wider (Figure 1, *b*). However, even at sufficiently high values of current (270 A) and powder feed (3.3 kg/h) for 10 m/h rate, surfacing with oscillations allows eliminating noticeable penetration of base metal.

Increase of plasmatron oscillation frequency has very small effect on coefficient of bead shape (Figure 2), at that it rises due to very insignificant decrease of bead

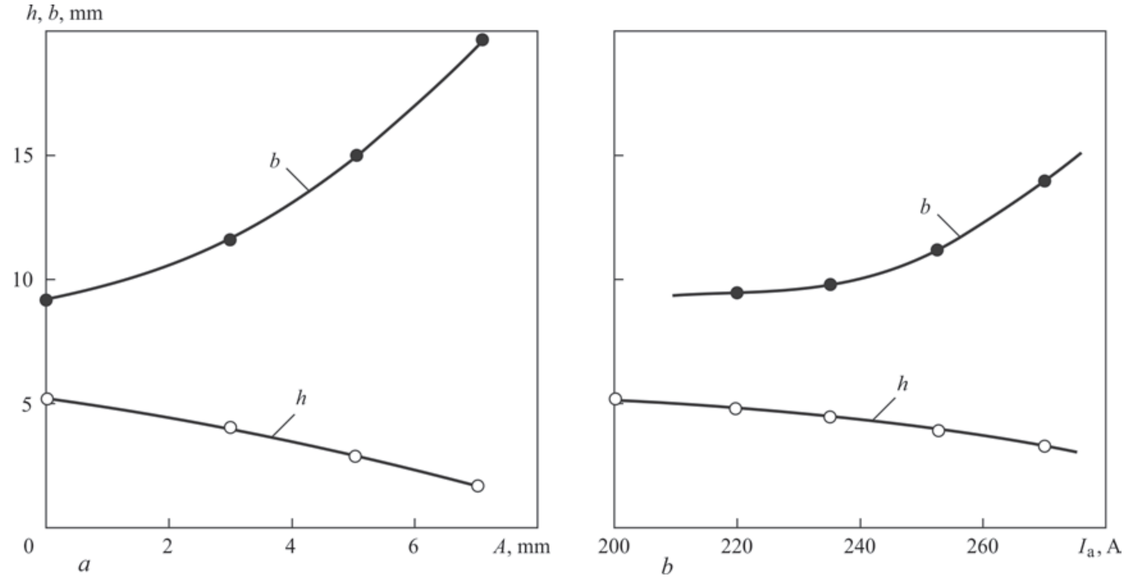

Figure 1. Effect of oscillation amplitude A (I_a — 245 A; oscillation frequency f = 70 min^{-1}) (*a*) and current I_a (A = 3 mm; f = 70 min^{-1}) (*b*) on height *h* and width *b* of deposited bead

height, i.e. bead becomes flatter. Good formation of bead edges is noted at more than 60 min^{-1} frequency.

A microstructure of deposited metal at values of plasmatron oscillation amplitude 0–3 mm differs by coarse grain (Figure 3, *a*). Portion of fine, almost equiaxial grains (Figure 3, *b*) rises considerably at 5 mm amplitude. In surfacing without oscillations they are only present in insignificant amount close to fusion line and in beads' surface zone.

The next step was dedicated to investigation of effect of plasmatron oscillation frequency on nature of base metal penetration and chemical and structural inhomogeneity in zone of joining of base and deposited metal along surfacing direction. The experiments were carried out on the following modes, namely oscillation amplitude A = 10 mm; oscillation frequency f; sample 1 — 40 min^{-1}, sample 2 — 60 min^{-1}, sample 3 —

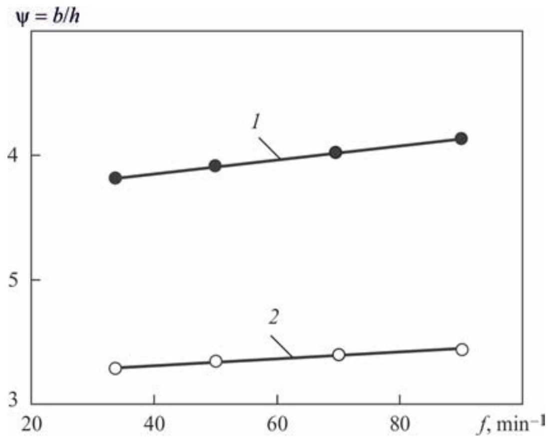

Figure 2. Effect of amplitude *A* and plasmatron oscillation frequency *f* on shape of deposited bead (I_a = 245 A): *1* — *A* = 5; *2* — 25 mm

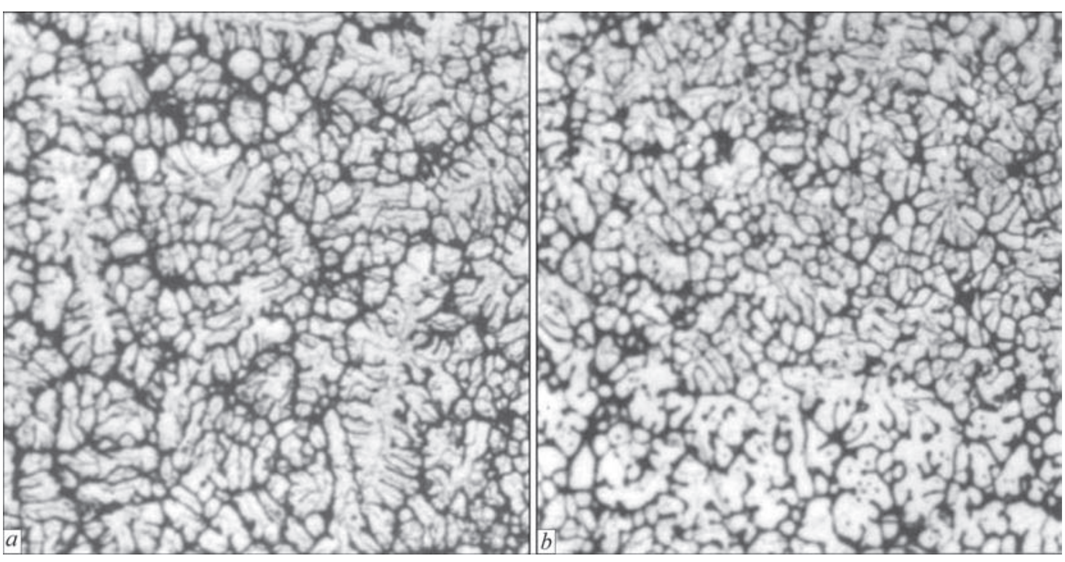

Figure 3. Microstructure (×300) of deposited metal of steel R6M5 type at I_a = 245 A: *a* — *A* = 0 mm, *f* = 0 min^{-1}; *b* — A = 5 mm, *f* = = 70 min^{-1}

Figure 4. Appearance of beads deposited by plasma-powder method with plasmatron oscillation at frequency, min^{-1}: *1* — 40; *2* — 60; *3* — 90) amplitude of oscillations — 10 mm)

90 min^{-1}; current — 180 A, surfacing rate — 10.5 m/h; powder feed — 3.0 kg/h, filler powder PR-Kh18N9. Figure 4 shows the appearance of deposited beads.

It can be seen from Figure 4 that increase of plasmatron oscillations frequency at constant amplitude of plasmatron oscillation and rate of surfacing improves formation of deposited beads, they become smoother. At that ripples on the bead surface correspond to plasmatron oscillation frequency.

Deposited beads were cut in the center along longitudinal axis. After grinding and polishing the samples were etched by electrolytic method in a solution of chromic acid and their metallographic examinations were carried out. Such preparation of the samples allowed evaluating structural and chemical inhomogeneity in joining zone of base and deposited metals along deposited beads' length.

Clear and relatively straight fusion line with small cavities (increase of penetration) in places of plasma arc passing is registered at ×20 magnification on longitudinal microsection of deposited bead 1 (Figure 5, *a*).

Crystallization of deposited metal is dendritic (Figure 5, *b*). The microstructure consists of austenite matrix and δ-ferrite precipitations along crystallite boundaries. Width of crystallites makes 20–35 μm. During transverse plasmatron movement at deposition of one layer on other there is a boundary between them and area of overlapping, moreover the boundary between two layers is preserved from the surface of deposited metal to fusion line with base metal.

A transition layer is located from the side of deposited metal. It has intermediate hardness between deposited and base metal hardness. Width of this layer makes 5–50 μm and depends on base metal penetration, i.e. change of composition of deposited layer in stirring of base and deposited metal. HAZ width for deposited bead 1 makes 2600–2700 μm.

Figure 6 shows macro- and microstructure of deposited bead *2*. In this case the fusion line of deposited metal with base one has wavy nature with alternating cavities and projections, repeating plasmatron oscillations (Figure 6, *a*). At that the cavities (local increase of penetration depth) correspond to places of direct passing of plasma arc and projections (local reduction of penetration depth) is the result of effect of periphery arc zone on base metal. Crystallization of deposited metal is dendritic, in the cavities the deposited metal has more dispersed cellular structure. Columnar crystallites grow from the fusion line with base metal to a sample surface and have 15–20 μm width.

In transverse movement of plasmatron at deposition of one layer onto another one, the obvious boundary between the neighbour layers (in contrast to bead *1*) is not registered that indicate good stirring

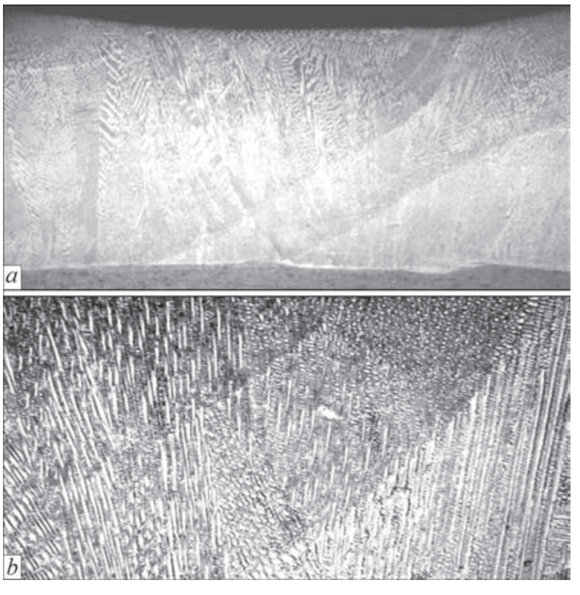

Figure 5. Longitudinal section of deposited bead *1*: *a* — macrostructure (×20); *b* — microstructure (×100)

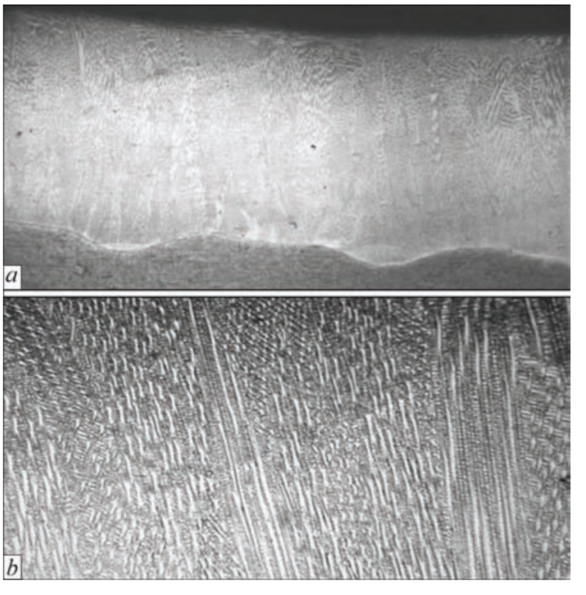

Figure 6. Longitudinal section of deposited bead *2*: *a* — macrostructure (×20); *b* — microstructure (×100)

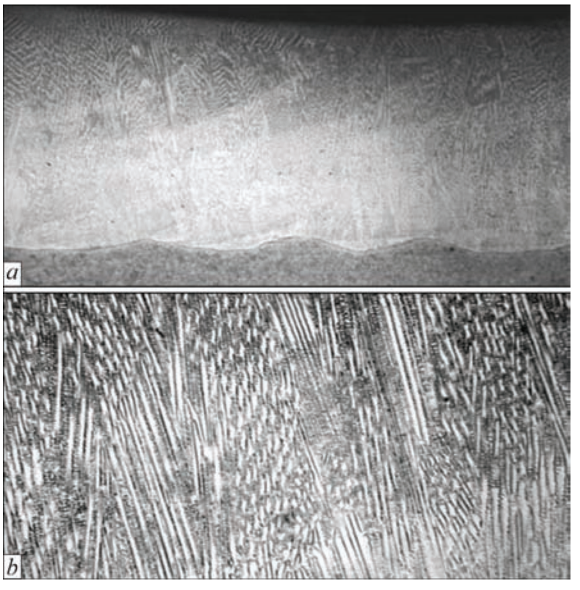

Figure 7. Longitudinal section of deposited bead *3*: *a* — macrostructure (×20); *b* — microstructure (×100)

of deposited metal (Figure 6, *b*). Width of the transition layer along the fusion line makes 2–40 μm. HAZ width is 3700–3800 μm.

Figure 7 presents macro- and microstructure of deposited bead *3*. The fusion line of deposited and base metal also has wavy nature, but with higher frequency of projections and cavities than in deposited bead *2* that is explained by high plasmatron oscillation frequency (Figure 7, *a*). A thin layer of alternating width from 2 to 20 μm is observed along the joining line with steel St3. HAZ width makes 4200–4500 μm. The extended crystallites are clearly seen. They are located normal to the fusion line and have 15–20 μm width. A microstructure of deposited metal of bead *3* is similar to the microstructure of deposited beads *1* and *2* and consists of austenite and δ-ferrite located on the crystallites boundaries.

Composition of deposited and base metal across their fusion line was investigated. The distance between neighbor measurements made approximately 2 μm (Figure 8). The examinations were carried out using Auger-microprobe Jamp-9500F of JEOL company, equipped with energy-dispersive X-ray spectrometer INCA Penta FETx3. Energy of primary electron beam made 10 keV at probe current 500 pA. Cleaning of sample surface by argon ions Ar^+ with 500 eV energy during 10 min (etching rate made 1 nm/min) was performed before the examination.

Sample *1* was used for investigation of distribution of main alloying elements (nickel and chromium) on straight section, projection and cavity in the fusion line of base and deposited metals (Figure 9).

In samples *2* and *3* deposited with higher plasmatron oscillation frequency it was difficult to choose straight sections of sufficient extension in the fusion line for analysis performance. This is the reason why distribution of main alloying elements (nickel and chromium) in these samples was investigated in a projection and cavity on the base and deposited metal fusion line (Figures 10, 11). These samples, in compar-

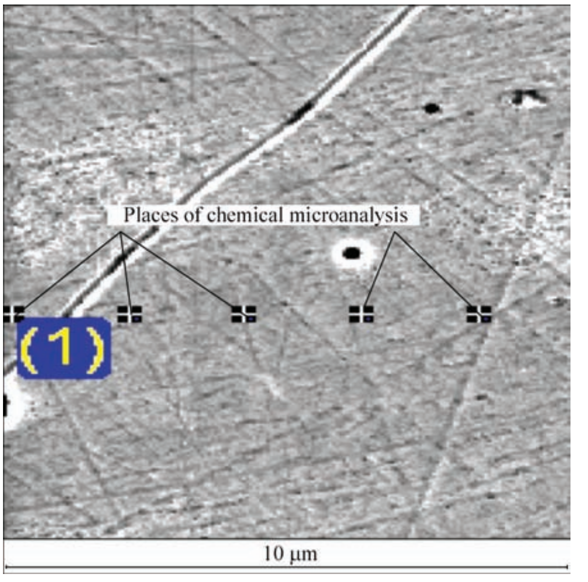

Figure 8. Illustration of performance of chemical microanalysis on Auger-microprobe

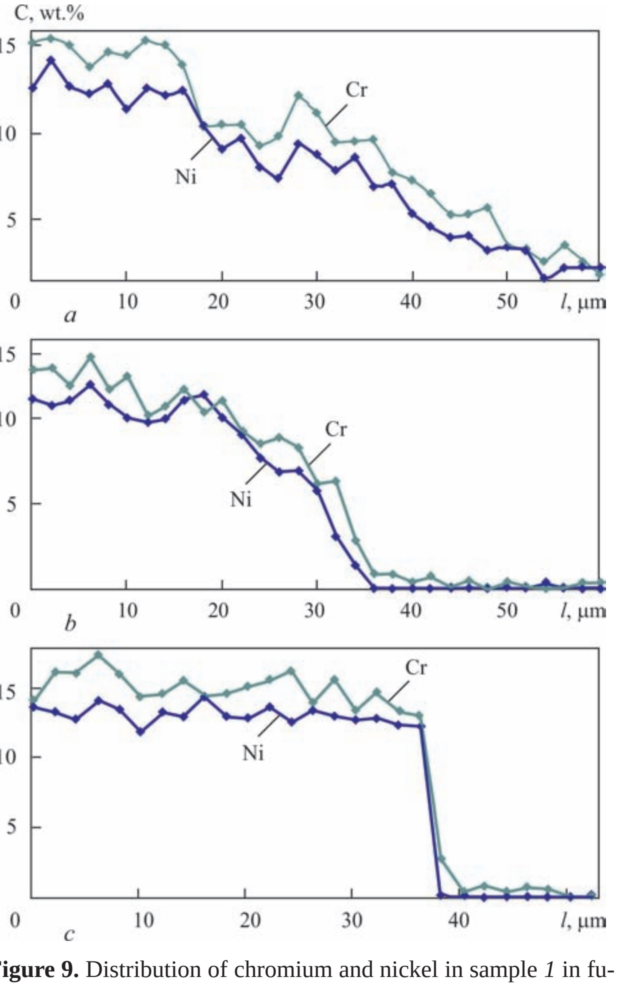

Figure 9. Distribution of chromium and nickel in sample *1* in fusion zone: *a* — straight section on fusion line; *b* — cavity on fusion line; *c* — projection on fusion line

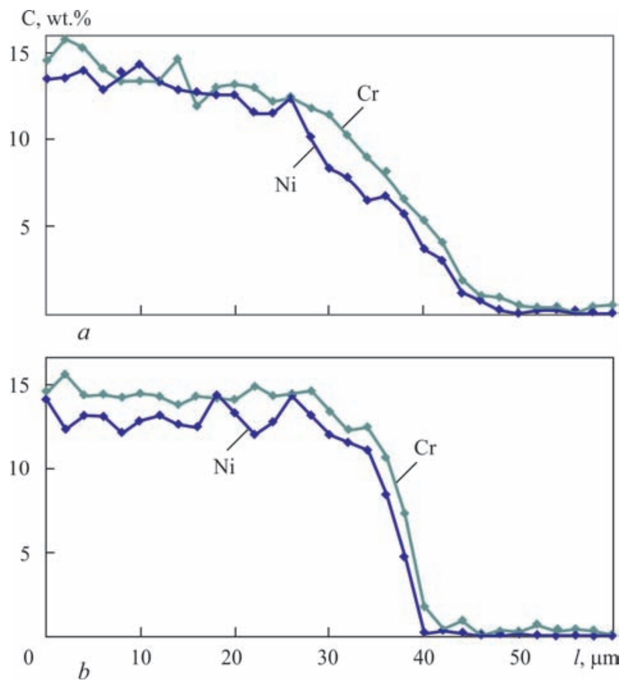

Figure 10. Distribution of chromium and nickel in sample *2* in fusion zone: *a* — cavity on fusion line; *b* — projection on fusion line

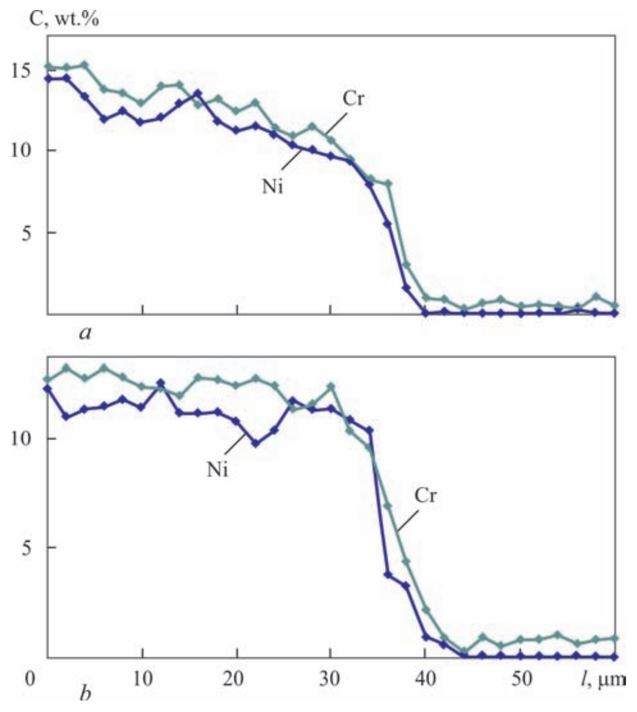

Figure 11. Distribution of chromium and nickel in sample *3* in fusion zone: *a* — cavity on fusion line; *b* — projection on fusion line

ison with sample 1, demonstrate more rapid change of content of the main alloying elements of deposited metal on the fusion boundary.

It should be noted that increase of oscillation frequency rises a rate of plasmatron transverse displacement, thus time of direct effect of plasma arc on the base metal is reduced. Apparently, it can be used for explanation of a fact that increase of plasmatron oscillation frequency promotes decrease of stirring of deposited and base metals in the projections as well as cavities on the fusion boundary and content of the main alloying elements rapidly changes from the deposited to base metal.

Conclusions

1. Effect of amplitude and frequency of plasmatron oscillations on formation of deposited beads was investigated in plasma-powder surfacing. At all other indices of surfacing mode being constant (deposition rate, current, powder feed rate) the most important effect on bead shape has the plasmatron oscillation frequency, i.e. its rise promotes increase of bead width and decrease of its height.

2. Investigations of effect of the plasmatron oscillation frequency on structural inhomogeneity of metal deposited by plasma-powder surfacing showed that:

• fusion line of deposited and base metals in longitudinal direction has wavy nature with frequency of projections and cavities repeating frequency of plasmatron oscillation; at that the cavities (local increase of penetration depth) correspond to trajectory of direct passing of plasma arc and the projections (local reduction of penetration depth) are the result of effect arc periphery zone on base metal;

• increase of plasmatron oscillation frequency from 40 to 90 min^{-1} promotes better stirring of deposited metal layers, balancing and refinement of structure on its section.

3. Increase of the plasmatron oscillation frequency provokes decrease of stirring of the deposited and base metals in the projections as well as cavities on the fusion boundary and content of the main alloying elements on this boundary rapidly changes from the deposited to base metal.

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