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Technology of Production of Refractory Composites for Plasma Technologies

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***Abstract*—On the basis of theoretical and experimental studies of intensive processes of vibration and hydrodynamic drawing, the technological scheme of production of bimetallic composites of the "zirconium or hafnium-zirconium core - copper shell" system is improved, substantiated experimentally, instrumentally drafted and implemented in production quantities. The scheme comprises hot pressing of the assembled workpiece on a bimetallic rod and further drawing with interpass annealing using the vibration of the drag and the hydrodynamic introduction of lubricant.**

Keywords— electrode, bimetal, strain centre, pressing, shell, connection.

I. INTRODUCTION

The productivity of plasma metal processing plants operated as part of automated complexes, as well as product quality largely depend on the resource stability of plasmatron electrodes. The main condition that determines the resource stability is the state of contact between the active element and the electrode body, depending on the method of their connection. To increase the resource stability of the electrodes by ensuring tight contact between the components, it is advisable to use in their manufacture composites in the form of bimetallic wiring system obtained by joint plastic strain of the core of refractory metal (active element) and plastic shell [1-7]. Works [8-11] demonstrated high efficiency of application for the manufacture of composites electrodes, in which zirconium or hafnium-zirconium alloys are used as the core, and the shell is made of zirconium bronze.

The purpose of the work is to create an effective technology for the production of composite materials based on refractory metals.

II. MATERIAL OF THE RESEARCH

The electrode includes a body and an active element pressed into it, which is obtained by cutting a special wire-composite of the «zirconium alloy-zirconium bronze» system. One of the important problems is to ensure reliable electrical contact between the composite components – refractory zirconium alloy core and zirconium bronze shell. This so-called «metallurgical» contact is provided by joint plastic strain (pressing, drawing) of the core and shell.

A known technical solution which ensures close the core and the shell contact is the placement of an intermediate layer of metal between them which has strength and ductility, intermediate between the respective characteristics of the core and the shell. In our case, the method of production of electrodes from zirconium alloys involves the use of composite workpiece for plastic strain without an intermediate layer, but under the condition of composite strain in a sharp decrease in external friction during tool vibration and hydrodynamic supply of oil to the contact surface of the deformation center [12-19].

The analysis of kinematic and force conditions of straining of the composite with a soft shell and a harder core was performed for the case when the contact surface of the strain centre has a sliding. In fig. 1 the velocity field at the strain centre inlet during the straining of the composite with a hard core and a softer shell is shown.

Rate components in the shell layer:

$$V_r = -V_r(r,\theta); \qquad V_0 = -V_\lambda = 0 .$$

To determine the rate dependence V_r on the coordinates, we use the continuity equation in the following form $\partial(rV_r)/\partial r = 0$.

Its overall solution is as follows $V_r = \varphi(\theta)/r$.

Strain rates are the following

$$\varepsilon_r = \partial V_r / \partial_r = -2\varphi(\theta)/r^2 ;$$

$$\varepsilon_{\theta r} = \varepsilon_{\lambda\lambda} = \varphi(\theta)/r^2 ;$$

$$\varepsilon_{r\theta} = -\varphi_1(\theta)/r^2 .$$

Intensity of strain rates

$$\varepsilon_i = \sqrt{3\varphi^2(\theta)+\varphi_1^2(\theta)} \Big/ \sqrt{3}\, r^2 .$$

Tangential stress in the shell layer

$$\tau = \mu_i \varepsilon_{r\theta} = \sigma_s^{'} \varphi_1(\theta) \Big/ \sqrt{3\varphi^2(\theta)+\varphi_1^2(\theta)} \cdot \sqrt{3}, \qquad (1)$$

where $\sigma_s^{'}$ is the yield strength of the shell material, which is taken independently from the coordinate r.

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When determining the functions $\varphi(\theta), \varphi_1(\theta)$, the sliding speed is expressed through the V_0 composite feed rate and the coefficient of tangential stress m, the value of which can range from zero (in the complete absence of contact friction) to one (with full adhesion on the contact surface).

Thus, the boundary condition for the separation surface between the shell and the core is

$$r = r_0; \ \theta = \theta_0; \ V_r = -V_0.$$

Under the linear law of velocity change along the shell thickness we obtain:

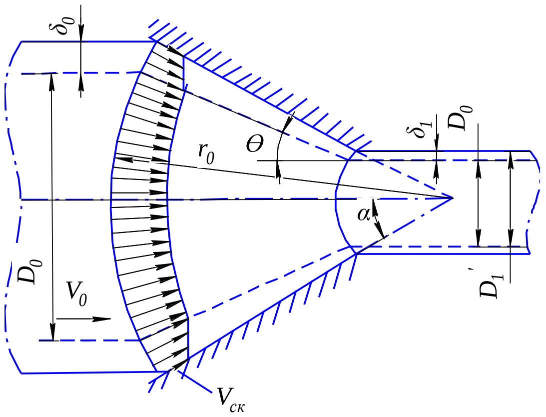

Fig. 1. Velocity space at the strain center inlet

$$\varphi(\theta) = -2V_0\left[1 - m\left(1 - \frac{\alpha - \theta}{\alpha - \theta_0}\right)\right] r_0^2 / \text{r}.$$

Then, according to (1)

$$\tau = m\sigma_S' / 12\left[(\alpha - \theta_0)(1 - m) + (\alpha - \theta)m\right]^2 + m^2\sqrt{3} \quad (2)$$

This formula takes into account, along with the characteristic of the strength and the relative shell thickness $\delta / V_0 \approx \alpha - \theta_0$, the conditions of sliding on the contact surface – through the coefficient m.

The friction stress at the contact is determined according to (2) by accepting $\theta = \alpha$:

$$\tau_K = m\sigma_S / \sqrt{12(\alpha - \theta_0)^2(1 - m)^2 + m^2}\sqrt{3}$$

The tangential stress at the interface is obtained from (2), taking $\theta = \theta_0$:

$$\tau_1 = m\sigma_S' / \sqrt{12(\alpha - \theta_0)^2 + m^2}\sqrt{3},$$

Thus, having $m \neq 0$ $\tau к < \tau_1$.

This allows to conclude that the plastic displacements in the layer of the soft shell are equivalent to the reduction of contact friction forces during pressing and drawing.

Since $m = f'\sqrt{3}$, where $f' = \tau_K / \sigma_S'$ is the coefficient of contact friction, the values of the contact friction coefficient during pressing must be larger than during drawing.

The analysis performed led to the conclusion that in the composite the use of a softer shell relative to the core significantly improves the composite strain conditions by pressing and drawing [20-29].

The developed technological scheme for obtaining composites [30-32] includes operations of manufacturing a composite workpiece (the core – zirconium alloy 110, the shell – zirconium bronze BrCr 0.1); hot pressing of the compound workpiece on a bimetallic rod with the diameter of 16 mm; vibration drawing of a bar to a diameter of 2.5 mm; hydrodynamic drawing of bimetal-left wire to a diameter of 1 mm.

To study the influence of the strain scheme on the quality of contact between the core and the shell, in the technological scheme the process of rotational forging was used as an option. Therefore, in the range of diameters of 2.5-1 mm, bimetal strain was carried out according to two schemes: according to scheme "A" as rotational forging to a diameter of 1.8 mm and hydrodynamic drawing to the final diameter; according to scheme "B" as exclusively hydrodynamic drawing.

The materials of the initial components of the composite workpiece had the following chemical composition (wt.%). Zirconium bronze of the shell: Zr-0.06-0.15; impurities, not more than 0.1; Cu-the rest. Alloy 110 of the core: Nb-1.1; Al-$8\cdot10^{-3}$; N-$6\cdot10^{-3}$; C-$2\cdot10^{-3}$;; Zr- the rest.

The ratio rating between the diameters of the shell and the core of the composite workpiece is determined by controlling the design of plasmatron electrodes. Thus, the diameter of the compound workpiece taken (85 mm) is determined based on the technological measures of the hot press. The diameter d_0 of the composite workpiece core was determined through the draft μ of the composite workpiece during its strain on the final composite with a diameter of 1 mm (table 1). Based on the specified core diameter d_1 in the final, composite is found as $d_0 = d_1\sqrt{\mu} \cong 66$ mm. In the manufacture of the compound workpiece, the actual core diameter was taken as equal to the calculated one [33-36].

According to the technological scheme, a composite workpiece and composites were made from it with actual diameters of 2.5 mm. The actual diameters of the core in composites were determined by metallographic means, fig. 2.

The data of calculations of core diameters and their measurements on metallographic sections under a microscope are given in table 1. The total strain of the compound workpiece required to obtain a composite with the desired core diameter can be determined with satisfactory accuracy by calculation.

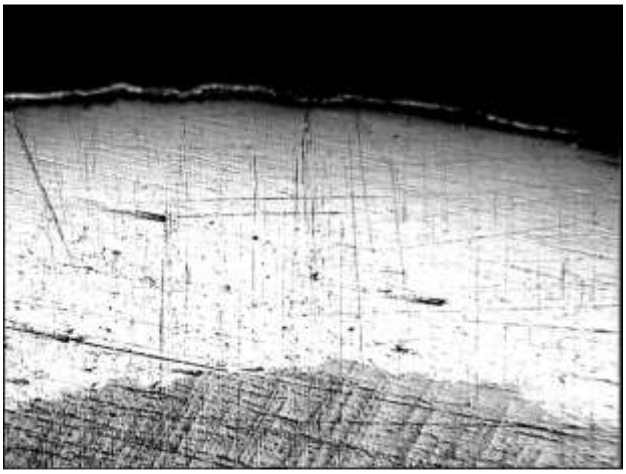

Fig. 2. Metallographic determination of the actual core diameter and shell thickness in the composite

TABLE 1 – CALCULATED AND FACTUAL VALUES OF CORE DIAMETER IN COMPOSITES

Compound workpiece – composite		Core, Ø,мм	
Composite fact. Ømm	Draft ratio	Calculate.	Actual
85	1	66.02	66.00
2,5	1158.1	1.94	1.93
1.02 «A»	6944.44	0.8	0.82
1.03 «B»	6810.25	0.8	0.83

III. RESULTS AND DISCUSSION

A set of industrial technological equipment has been selected for the implementation of the improved technological scheme. Highly capacity technological processes of vibration deformation and hydrodynamic drawing are included in the design of machines for obtaining composites [37-39].

Since the final technological strain operations are responsible for the formation of a tight contact between the core and the shell, in the range of diameters of 2.5-1 mm, the study of the evolution of microstructure, chemical composition and metal surface in the transition zone between the core and shell during processing was carried out.

To establish the regularities of the strain of the «metallurgical» contact during the composite strain, composites of several diameters were used in these experiments. In the samples of the composite in the range of diameter 2.5 – 1.8 mm in the transition zone, the areas up to 1.5 μm wide where contact is absent are found. In the composite strain process to the diameter of 1 mm, these areas are closed leaving only small micropores [40]. Thus, there is a certain general strain of the composite, which provides a "metallurgical" contact between the components of the bimetal, Figure 3.

Comparison of the microstructures of the transition zone in the composites obtained according to schemes «A» and «B» indicates the beneficial effect of rotational forging in the final stage of composite strain on the formation of dense, without voids and pores, contact between the core and shell. This is due to the «softer» scheme of the stress-strain state of the metal during rotational forging compared to drawing [41-43].

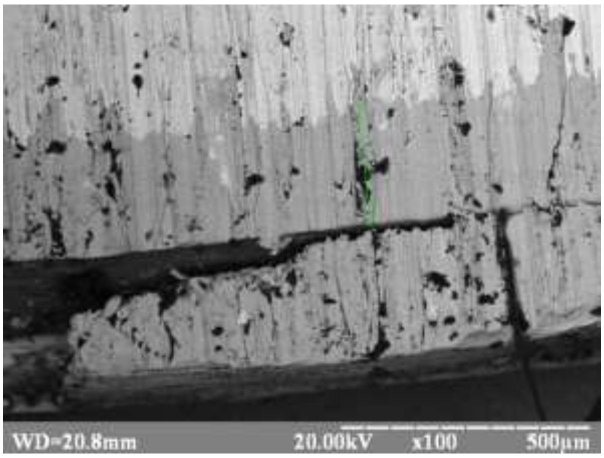

Fig. 3. The structure of the bimetallic wire contact zone

Composites with a diameter of 2.5–1 mm active element for electrodes plasmatrons of plasma cutting and plasma-mechanical processing of metals are produced. The electrodes are obtained by making a copper body not lower than M–2 and pressing an element obtained by cutting the composite to indexing length into it. The electrodes are operated under the following conditions:

– type of current–direct;

– operating current range, A – 100-400 at PV = 100%;

– plasma–forming gas–oxygen, air;

– cooling–forced water, 5 l /min;

– climatic execution – UHL under State Standard 15150.

It is possible to make electrodes by stamping them directly from the composite segments. In this case, the shell diameter is taken under the condition of forming from the electrode body shell volume.

IV. CONCLUSIONS

As a result, the industrial technology of obtaining the «zirconium alloy-zirconium bronze» bimetallic composites intended for the production of active elements of plasmatron electrodes on the working current of 100-400 A has been investigated and improved.

Based on theoretical and experimental studies of intensive processes of vibration and hydrodynamic drawing, the technological scheme of production of bimetallic composites of the «zirconium or hafnium-zirconium core – zirconium bronze shell» system has been improved, experimentally substantiated, hardware designed and implemented on an industrial scale. The scheme provides for hot pressing of the compound workpiece on a bimetallic rod and subsequent drawing with intermediate annealing using the vibration of the drag and hydrodynamic introduction of oil.

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