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Durability of non-consumable electrodes of different designs in welding with a low-ampere arc in helium

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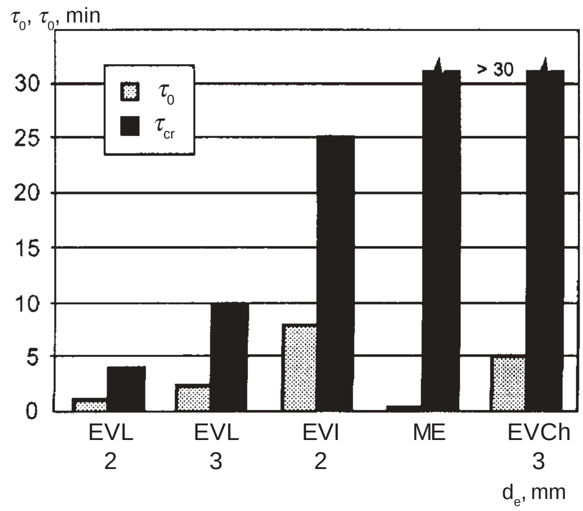
The quality of joints obtained in non-consumable electrode welding greatly depends on the condition of the working section of the electrode. The destruction of the initial geometry of the electrode results in a reduction of the spatial stability of the arc and in changes in the thermal and force effect on the welded metal.[1] The failure of tungsten electrodes during welding results in the formation of tungsten inclusions in welded joints.

In Ref. 1–7, the following types of failure of tungsten electrodes in welding were described: melting, erosion, formation of deposits of different shapes on the working section of the electrodes or the so-called corona represented by a ring of dendrite-like crystals of pure tungsten, situated at a certain distance from the zone of attachment of the arc. In contrast to ‘ corona formation’, which is explained by the evaporation of tungsten from the surface of the electrode in sections with the maximum temperature and followed by condensation of tungsten in colder regions,[4, 6] the formation of the built-up regions is usually associated with the effect of the anode material. The reasons for the formation of the built-up regions include the variation of surface energy in the contamination of tungsten electrodes with the anode material,[1] and also the formation of chemical compounds with heat resistance lower than that of tungsten.[3, 7]

The data in the majority of the previously mentioned investigations relate to the high-current (50–500 A) arc, whereas the negative effect of the variation of the shape of the working section of the electrodes on the quality of weld formation is most evident in the welding of thin sheet materials with the low-ampere arc (less than 25 A). This is associated with high sensitivity of the process to changes in the conditions in the welding zone. The aim of the present work was the examination of the durability of non-consumable electrodes of different grades and design in welding with the low-ampere arc in helium.

Investigations were carried out with electrodes EVCh, EVL and EVI of the conventional design with a diameter of 2 and 3 mm, the angle of grinding of the working section $\alpha = 30°$, and also with multi-rod electrodes (Patent 2170652, Russian Federation) where the working section consists of several thin tungsten rods. In the experiments, the working section consisted of two rods of commercial purity tungsten VRN, diameter 0.3 μm. The anodes were represented by sheets of Kh23Yu5 precision alloy, with a thickness of 0.9 mm, secured in a copper watercooled system. The length of the arc was 1.5 mm. The shielding gas was represented by helium, grade A, oxygen content 0.0001%. The consumption of the gas was constant, 10 l/min. The composition of experimental equipment included MBS-9 microscope, fitted with a light filter for the examination of the condition of the electrodes directly during arcing. The condition of the working sections of the electrodes after arc extinction was investigated visually at a magnification of 10. The phase and chemical composition of the material of the deposits, formed on the electrodes, was determined by the methods of extra diffraction and x-ray spectrum microanalysis. The durability of the electrodes was evaluated on the basis of the operating time of the electrode up to the formation of visible changes of the geometry of the working section τ_0 and up to failure τ_{cr}.

The effect of the design and grade of the non-consumable electrode on τ_0 and τ_{cr} is shown in Fig. 1. It may be seen that the EVL electrodes are characterised by very low durability: $\tau_0 \leq 1$ min. Subsequent stages of failure are shown in Fig. 2. In operation of the electrode during this period of time (arc current 20 A), a neck starts to form at a distance of 1–1.5 mm from the working sheet of the electrode (Fig. 2**a**, indicated by the arrow). The neck becomes very distinctive after the operation of the



1 *Dependence of τ_0 and τ_{cr} on the design, grade and diameter of the nonconsumable electrode (I_a = 20 A).*

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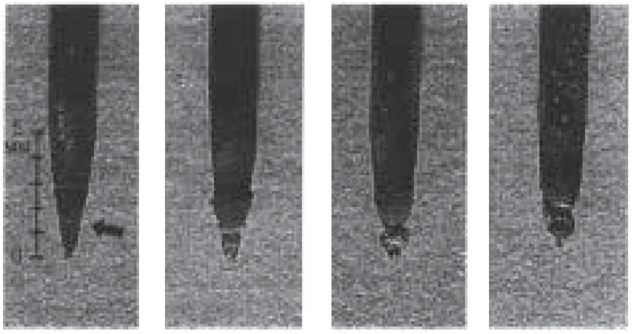


a b c d

2 *The variation of the shape of the working section of the EVL electrode with a diameter of 2 mm in burning of the arc for 1 (**a**), 2 (**b**), 3 (**c**) and 4 min (**d**).*

electrode for 2 min (Fig. 2**b**). The area in the vicinity of the make is covered with the fine melt droplets, moving actively during arcing on the surface of the electrode. This is accompanied by the melting of the working tip (the tip of the conical section) and by the formation of a small 'corona' above the neck. Increasing operating time to 3 min. results in the formation of deposits of irregular shape in the working section of the electrode below the neck (Fig. 2**c**). The size of the deposits increases rapidly with a simultaneous reduction of the neck diameter.

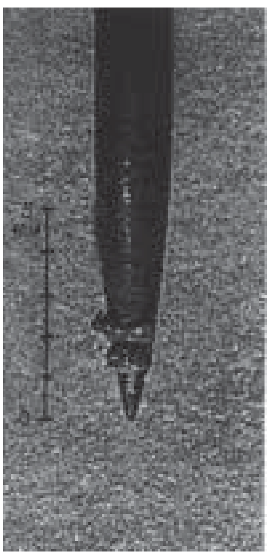
The formation of the deposits is accompanied by the rapid wandering of the arc as a result of the displacement of the cathode spot on the surface of the deposits. After 3.5–4 min, the deposits separate and, consequently, the initial geometry of the working section of the electrode is completely disrupted (Fig. 2**d**). During further operation of the electrode, a new neck starts to form at a certain distance from the separation area and the process is repeated. Time τ_{cr} slightly increases with increase of the diameter of the electrode (Fig. 1).

For the electrodes produced from yttrium-doped tungsten, the values of τ_0 and τ_{cr} equal 8 and 25 minutes, respectively. The variation of the form of the working section in operation of such electrode with a diameter of 2 mm for 12 minutes at a current of 20 A consists of the formation of a ring-shaped deposit at a certain distance from the working tip (Fig. 3), and the conical section does not contain any visually visible traces of failure.

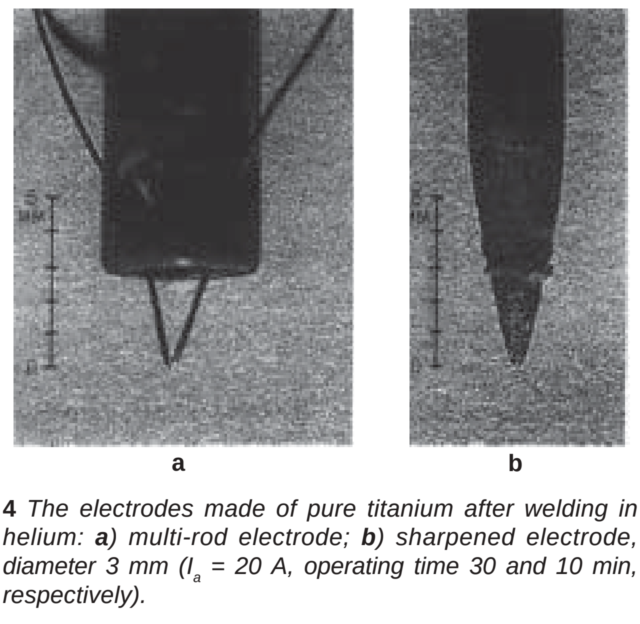
The nature of changes on the working section of multi-rod electrodes is different. After excitation of the arc, a melt droplet forms on the working end. The size of the droplet does not exceed the diameter of the tungsten rod. In certain cases, the rods melt resulting in the formation of the working section which has almost no effect on arc voltage and the durability of the electrode. Because of the small volume of the molten electrode metal, there is no separation of the droplet, and the electrode operates without further changes of the shape of the working section during a long period of time (30 min). The external appearance of the electrode after operation is shown in Fig. 4**a**.

The electrodes produced from pure tungsten EVCh with a diameter of 3 mm are also characterised by very high durability. The variation of the geometry of the working section of these electrodes takes place by the mechanism of 'corona formation'. There is slight melting of the working section which, however, does not progress with time. The external appearance of the electrode after operation for 10 minutes at a current of 20 A is shown in Fig. 4**b**.

The x-ray diffraction analysis of the material of the deposits formed on the activated electrodes, examined using DRON-3 diffractometer, shows the presence of the single-phase structure based on tungsten with a large change of the crystal lattice parameter: a = 0.3146 nm in comparison with 0.3165 nm in the case of pure tungsten. X-ray spectrum microanalysis, carried out in JEOL JSM-35CF scanning electron microscope with a 4-crystal spectrometer was used to determine the following composition of the material of the built-up areas (per cent): 96.6 W, 1.75 Fe, 1.3 Cr, 0.35 Al. This explains the decrease of the crystal lattice parameter with the formation of the solid solution by means of the smaller atomic radii



3 *EVI electrode with a diameter of 2 mm after operation for 12 minutes at I_a = 20 A.*



a b

4 *The electrodes made of pure titanium after welding in helium: **a**) multi-rod electrode; **b**) sharpened electrode, diameter 3 mm (I_a = 20 A, operating time 30 and 10 min, respectively).*

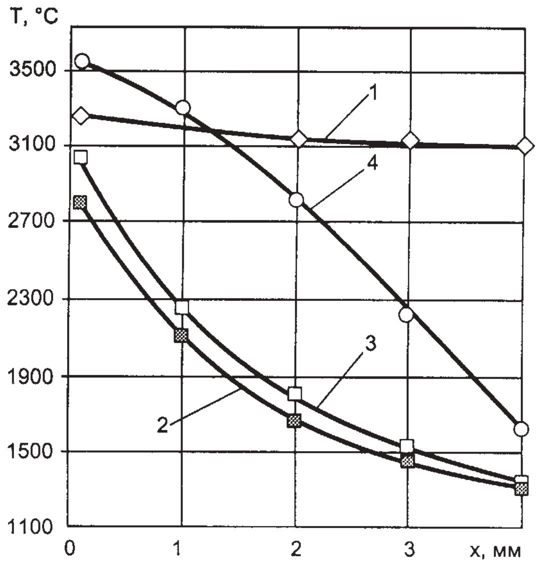
of iron, chromium and aluminium (0.172, 0.185 and 0.182 nm, respectively) in comparison with tungsten (0.202 nm).

Evidently, the following conditions must be satisfied for fracturing the electrode as a result of saturation of tungsten with the elements included in the composition of the anode material. Firstly, the presence of a sufficiently large number of ions of these elements in the arc plasma in the vicinity of the electrode. This is possible only in the evaporation conditions, i.e. in the presence of a molten metal pool on the anode. Secondly, the presence on the surface of the electrode of regions with the temperature below the boiling point of the evaporating elements on which the condensation of the latter would take place.

In argon-shielded arc welding, the transfer of anodr material to the electrode takes place at a very small length of the arc gap, not greater than 0.3 mm,[7] which makes it possible to prevent contamination of the electrode as a result of increasingly arc length. As indicated by Figs. 2 and 3, the region of the most intensive formation of the built-up metal is situated at a distance of 0.5–1.5 mm from the working end of the electrode. Thus, taking into account the large length of the arc in the experiments, it may be concluded with a high degree of reliability that in arc welding in helium the intensity of evaporation of the anode material is considerably higher in comparison with welding in argon. The increase of the arc length to 3 mm does not increase the durability of the working section of the electrode and, consequently, in arc welding in helium the contract of the surface of the electrode with the vapours of the anode material is obviously unavoidable.

In particular, in welding with the low ampere arc the activity of condensation of the vapours of the anode material on the surface of the electrode is the highest. This is due to the fact that at high values of arc current, the temperature of the working section is higher than the boiling point of the evaporating elements (2870 °C in the case of iron, 2680 °C for chromium, and 2467 °C for aluminium).[8] According to the result of pyrometric measurements, the temperature of the sharp end 4 mm long in the EVL electrode with a diameter of 3 mm (α = 45°) in welding with a current of 450 A monotonically decreases from 3250 °C at the working end of the electrode to 3100 °C in the area of transition from the sharp tip to the body of the electrode (Fig. 5). In welding with the low-ampere arc, the temperature of the working sections of the electrodes in these points is considerably lower. The lowest values were recorded in the working section of the yttrium-doped electrode, whose temperature decreases in the range from 2800 °C in the vicinity of the working end two 1300 °C in the area of transition from the sharp end to the body of the electrode. The temperature of lanthanised electrodes is slightly higher, from 2950 to 1350 °C. The difference in the temperature is of the working sections of the yttrium- and lanthanum-doped electrode increases slightly when approaching the working end of the electrode.

The curve of distribution of temperature along the length of the working section of the multi-rod electrode (Fig. 5, curve 4) is positioned considerably higher. For example, if at a distance of 4 mm from the working end of the electrode the temperature is 1750 °C, than in the immediate vicinity of the electrode it is 3550 °C, which is higher than the melting point of tungsten (3420 °C).



5 *The distribution of temperature in the working section of EVL electrode with a diameter of 3 (1) and 2 mm (3), EVI electrode with a diameter of 2 mm (2) and multi-rod electrodes (4): 1)* I_a *= 450 A; 2–4) 20 A.*

The resultant relationships show that the temperature of the working sections of the electrodes of conventional design in welding with the low-ampere arc is lower than the boiling point of the elements evaporating from the anode at a distance of 0.5 mm from the working end of the electrode. This corresponds to the boundary of the zone of intensive formation of the built-up metal. In contrast to the electrodes of conventional design, the temperature of the working section of the multi-rod electrode exceeds the boiling point of the elements of the material of the anode along the entire length of this region. The higher temperature of the working section evidently prevents the condensation of the vapours of the anode material resulting in high durability of the multi-rod electrode.

These experimental results show that a reduction in the durability of the nonconsumable electrodes in welding with the low-ampere arc in helium is caused by the presence of activating additions in the electrode. The failure of activated tungsten electrodes takes place as a result of the changes in the physical properties of the electrode material in the transition from the binary systems $W–La_2O_3$ and $W–Y_2O_3$ to multicomponent systems W–La–O–Fe–Cr–Al and W–Y–O–Fe–Cr–Al in the absence of any chemical interaction of the elements, condensed on the surface of the electrode, with oxygen or tungsten.

There are two methods of increasing the durability of the nonconsumable electrodes in welding with the low-and the arc in helium: the application of electrodes not containing activating additions, of the formation of conditions in which the temperature of the working section of the electrode is higher than the boiling point of the elements, included in the composition of the anode material, along the entire zone of possible condensation.

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The second of the proposed methods may be realised by the application of electrodes whose design ensures almost uniform heating of the working section in combination with high-density of current of the electrode. These conditions are satisfied by the multi-rod electrodes with the working section made of 1–3 (depending on current) tungsten rods with a diameter of 0.15–0 .30 mm, and also the sharp end electrodes of small diameter (0.8–1 .0 mm).

Conclusions

1 The failure of the working sections of activated nonconsumable electrodes in welding with the low–ampere arc is caused by the changes in the physical properties of the electrode material in transition to the multicomponent metallurgical systems containing both elements included in the composition of the electrode and the elements evaporating from the anode.

2 The increase of the surface life may be achieved by replacing activated electrodes by electrodes made of pure tungsten and also by the application of electrode whose design results in heating of the working section to the temperature preventing the condensation of the vapours of the anode material.

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