Electro-erosion resistance of different electrodes materials for plasma generators

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Abstract. The experimental results of the hollow electrodes erosion resistance considering a pilot arc re-ignition during plasma torches operating, are presented in the paper. A high voltage alternating current oscillator is used to simulate an initial process instability. The electrical circuit of the experimental setup with a pulsed discharge current up to 2 kA with time parameter 8/250 and a follow current of 800 A at industrial frequency is described. Four electrodes materials of tungsten (W), iron (Fe), copper (Cu), copper with a sprayed nickel+iron powder (Cu-Ni-Fe) are investigated. X-ray patterns of the different electrode surfaces are demonstrated after 4–9 pulses and one pulse with follow current impacts. The electric charge is calculated by integrating the obtained discharge current to assess the erosion coefficient. The following decreasing order of the electrical erosion resistance is determined: W - Fe - Cu-Ni-Fe - Cu.

Keywords: plasma generators, electrodes, electro-erosion, plasma arc.

1. Introduction

Plasma torches have widespread application in additive technologies for metal powders dispersion, metal cutting, coating, and toxic waste processing [1–4]. All of issues require the high reliability of plasma generators. The growth of electrodes performance and their electrical erosion resistance considering transient processes during arc re-ignition and powerful heat-stressed influence of thermal plasma, is a way to ensure continuous operation lifetime of plasma installations [5–7].

The electrodes must withstand a high emission current density [8]. The emission current is generally provided by thermal emission of electrons from the cathode spot at the conjunction point of the electric arc [9]. The thermal emission current density rises with temperature increasing and thermionic work function potential barrier reduction, according to Richardson-Dushman equation:

$$j_e = A \cdot T^2 \cdot \exp\left(\frac{-W}{k_B \cdot T}\right) \tag{1}$$

where j_e is the current density of the emission, A is universal Richardson's constant ($A = 1.2 \cdot 10^6$ A/m$^2 \cdot$K^2), T is temperature (K), W is the work function of the cathode material, k_B is the Boltzmann constant.

To ensure effective operating currents of the electric arc (about 108 A/m^2), the cathode surface temperature must be higher than 3600 K. Refractory materials with high melting point based of tungsten with components of oxides of thorium, zirconium, hafnium, yttrium are usually used as cathode [9]. The low work function of electrons of such materials allows to decrease the cathode temperature while maintaining the required current density. However, a decrease in the thermal and electrical conductivities of the materials reduces the power of the plasma torch and its performance.

The choice of material depends on the properties of the working gas [6]. Working gases of plasma-chemical processes can be conditionally divided into oxidizing (oxygen, carbon dioxide, air, etc.) and non-oxidizing (nitrogen, helium, argon, etc.). The appearance of a small amount of oxygen (air) in the plasma-forming gas leads to a catastrophic increase in the erosion of electrodes of some materials (tungsten, copper, etc.) [10]. The introduction of iron alloys or some refractory substances reduces the rate of the material evaporation in the process of plasma creating [6]. Besides, the area near the cathode is filled with a non-oxidizing gas as a protection in some plasma torches designs, and the working plasma-forming gas is fed directly into the arc channel [9].

An application of less refractory materials (for example copper-based alloys) for hollow cathodes with water-cooling is another way to solve the problem [6]. Reliable operation of the plasma torch with a hollow cathode is accompanied by a short-time fixation of the spot at the reference point of the cathode with a high current density and requires the obligatory movement (rotation) of the cathode spot [9]. The magnitude of the electrode erosion depends both on the power of the plasma torch and on the movement velocity of the cathode spot. In practice, the "jump" of the spot is provided by a vortex gas flow or magnetic action. The plasma torch power supply system is decisive for the stabilization of the arc current [11] when the reference points of the electric arc move, however, it is not always capable of ensuring the static and dynamic stability of the plasma torch arc. An auxiliary electrode as the pulse injector for arc ignition is used to form the pilot arc in some cases [12–15]. The accompanied instabilities could significantly influence on the hollow electrode erosion resistance and therefore on the plasma torch operation.

The paper is aimed at studying of the electro-erosion resistance of the hollow electrodes during an operation in the critical modes of pilot arc formation by a high-voltage discharge (oscillator) in order to increase the performance of the electrode system for plasma torches with powers from 100 to 500 kW [13].

2. Experimental stand

A scheme of experimental stand is presented in Fig.1. The generator module of follow current circuit consists of capacitors and inductors as well as charging and control units which are connected to a high-speed measuring system. The generator module consists of capacitors and inductors as well as charging and control units which are connected to a high-speed measuring system. High currents in the range of 10 kA over 5 ms can be realized with a specific combination of inductances and capacitances. With an initial voltage of up to 18 kV this kind of high current generator can be used to generate switching arcs of larger distance. Detailed description of the experimental stand is given in [16].
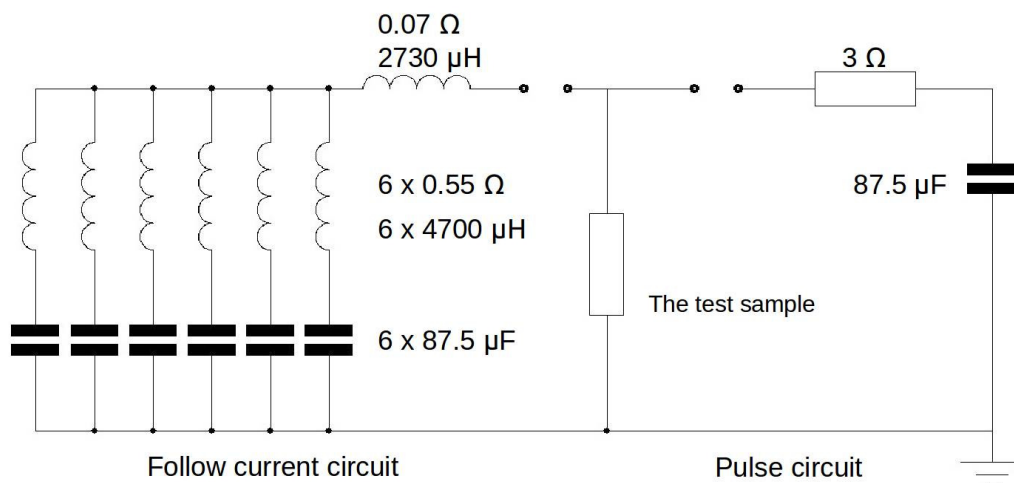

Fig.1. Electrical setup.

The workbench (Fig.1) provides the both pulsed waveform at the current level of 2 kA and follow current circuit of 800 A in 10 ms after the pulse with time characteristic 8/250. The distance between the electrodes is about 10 mm. An ignition wire between the electrodes is used to establish the arc, which has a limited impact on the first millisecond of the discharge only and does not affect the later progress of the arc discharge [16].

Fig.2 shows a sample of the pulse and follow current waveforms in the experiments. Several electrode prototypes were investigated: tungsten (W), iron (Fe), copper (Cu), copper with nickel+iron coating (Cu+Fe+Ni). The electrodes were loaded by current in ambient air. The experiments were carried out with photo and video fixation for electrode surface erosion by method of radiography.
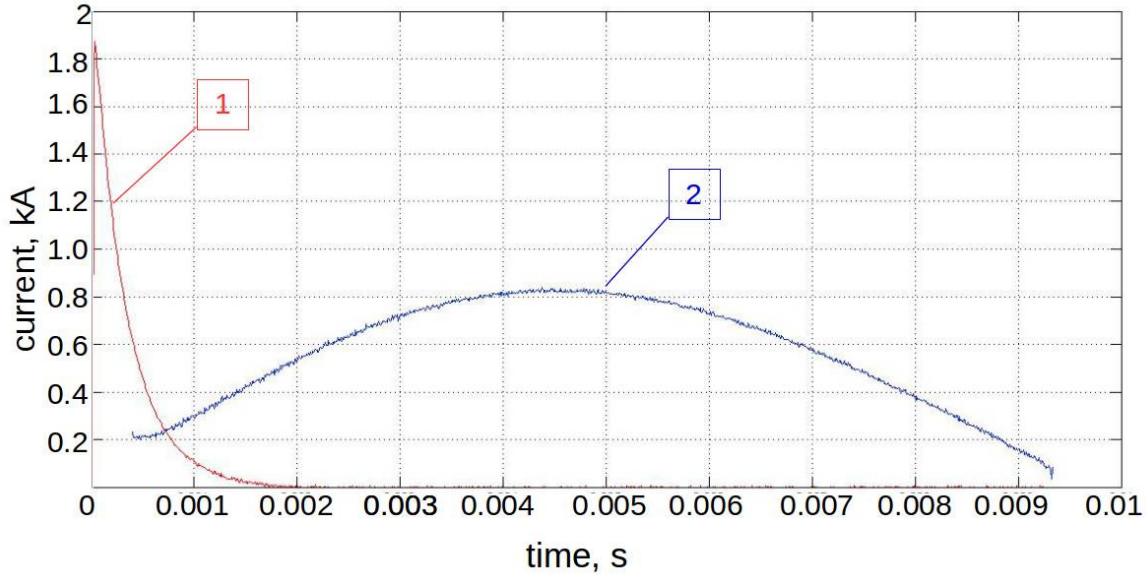

Fig.2. Pulse (1) and follow current (2) waveforms.

3. Results and discussion

The erosion coefficient k is the proportionality coefficient between volume of the electrode lost due to erosion (*V*) and the electric charge passed through the electrodes (Δq) [17]:

$$V = k \cdot \Delta q \tag{2}$$

The loss of electrodes was determined by measuring their mass on a Mettler AL 54 high-precision balance with subsequent conversion to volume. Measurement error does not exceed 1%.

The electric charge Δq was determined by integrating the discharge current using the measured oscillograms of the discharge current:

$$\Delta q = \int_0^t i(t)dt \tag{3}$$

The erosion coefficients for the materials under study are shown in Fig.3: $k_W = 0.4$ cm^3/C; $k_{Fe} = 2.5$ cm^3/C; $k_{Cu} = 4.8$ cm^3/C; $k_{Cu+Fe+Ni} = 6.4$ cm^3/C.

The X-Ray patterns of the different electrode surfaces are demonstrated in Fig.4–7 after 4–9 consequent pulses with time parameter 8/250 (left) and one pulse+follow current (right) accordingly. The Fig.4–7 illustrate an increase in electrodes erosion for all materials under the study due to arc re-ignition process, which leads to reduction of the electrodes lifetime.

The present study allows to predict the erosion volume versus the electric charge passed through the electrodes for different materials (W, Fe, Cu, Cu+Fe+Ni), when plasma torches operate in pulsed and transient modes of non-stationary conditions. The tungsten-electrode is determined to have the lowest erosion volume $\Delta V_W \sim 0.72$ mm^3 after 4 pulses (8/250) with arc voltage 1.5–3.0 V from investigated ones with $\Delta V_{Fe} \sim 2.42$ mm^3; $\Delta V_{Cu} \sim 4.3$ mm^3; $\Delta V_{Cu+Ni+Fe} \sim 2.45$ mm^3.
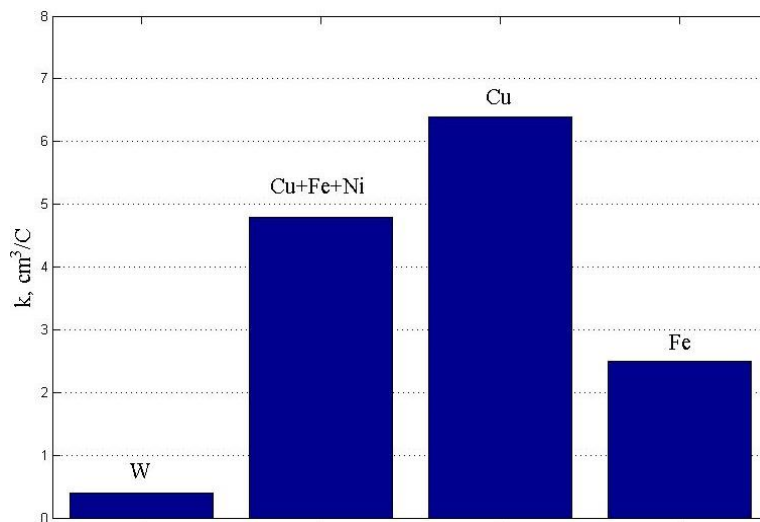
Fig.3. Erosion coefficients for different electrode materials.
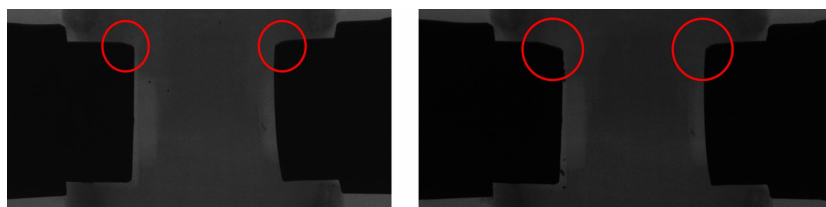

Fig.4. Tungsten-electrode surface after 9 pulses (left) and pulse+follow current (right) waveforms.
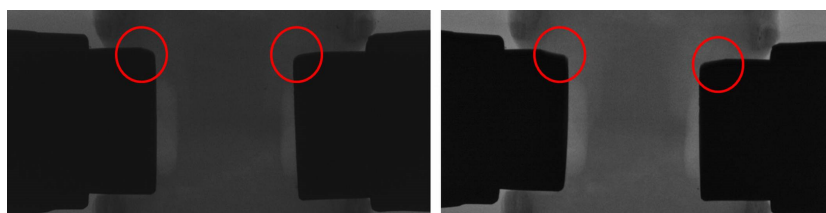

Fig.5. Iron-electrode surface after 6 pulses (left) and pulse+follow current (right) waveforms.
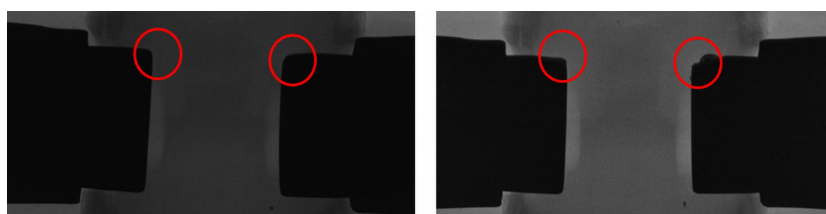

Fig.6. Copper-electrode surface after 6 pulses (left) and pulse+follow current (right) waveforms.
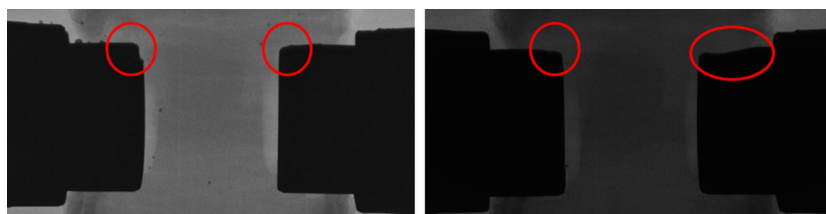

Fig.7. Copper with nickel+iron coating electrode surface after 4 pulses (left) and pulse+follow current (right) waveforms.
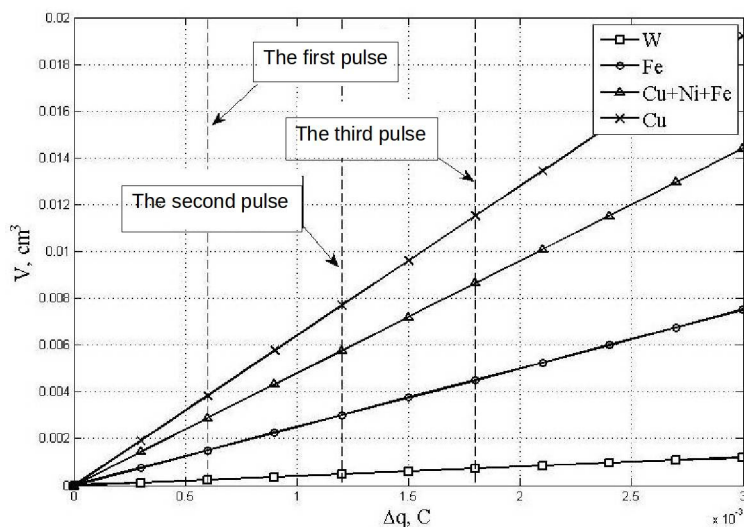
Fig.8. The electrodes erosion volume versus the electric charge passed through the electrodes.

Fig.8 shows the generalized values of volumetric losses of materials due to the erosion process depending on the number of current pulses.

4. Conclusion

The values of the erosion coefficients were established in the critical mode of the arc re-ignition, which corresponds to the values 0.4, 2.5, 4.8, 6.4 cm^3/C for tungsten (W), iron (Fe), copper (Cu), copper with nickel+iron coating (Cu+Fe+Ni) accordingly. The use of tungsten (W) as the material for hollow electrodes is investigated to be the most effective for plasma torches applications with powers from 100 to 500 kW. However, the use of various working gases requires additional investigations in the field of electro-erosion resistance of the hollow electrodes for arc plasma torches in a wide range of nominal parameters.

Acknowledgement

5. References

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