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Shielding methods of quasilaminar jets outflowing from plasma torch with interelectrode insert

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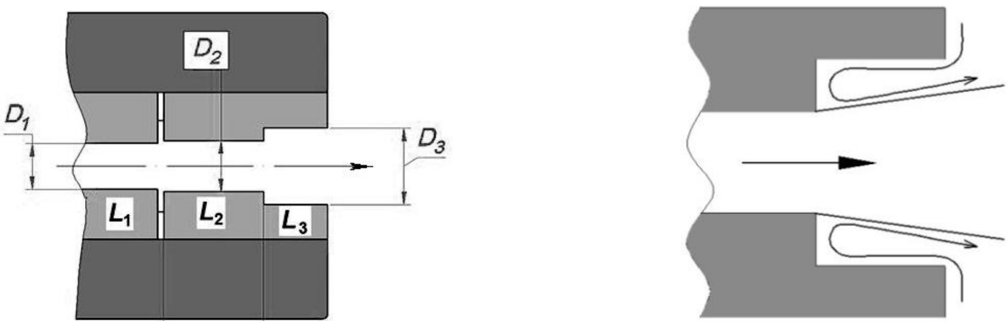
Abstract. Investigations of two methods of protection against mixing of surrounding air atmosphere with the free lengthy jets outflowing at low Reynolds numbers from plasma torches with interelectrode insertion (IEI) were carried out. The offered methods allow to significantly reduce the mixing of oxygen with plasma jets that gives a possibility of synthesis, treatment and spraying of powder materials, as well as melting of coatings critical to oxidation.

Up till now in practice of plasma spraying, synthesis and treatment of powder materials, as well as modifying of surface, including melting of coatings, the most popular were the plasma torches with self-stabilizing arc length generating turbulent plasma flows. Drawbacks of these plasma torches are discussed in paper [1]. In particular, they are characterized by high jet outflow velocity (up to 600 m/s and above) which results in small distances between the nozzle of plasma torch and the treated surface (~ 5–7 calibers), due to considerable dynamic pressure of the impinging jet the destruction of coating layer during its submelting can occur. At increase in the distance it is impossible to submelt the coating without significant thermal impact on the base, because due to intensive mixing of turbulent jet with the surrounding atmosphere, the extent of high-enthalpy core of the stream is small. Besides, this mixing leads to oxidation of the treated metal and cermet powders, as well as coatings at their submelting.

One of solutions to overcoming the specified drawbacks is the creation of stable quasi-laminar plasma flows of rather big extent outflowing from plasma torches at low Reynolds numbers. It allows to significantly reduce the mixing of surrounding gas both with the plasma jet and the area of its impingement on the surface. Plasma torches with IEI are perspective for implementation of such approach.



(a) (b)

Figure 1. Scheme of the backward-facing step forming nozzle **(a)** and of the flow in it **(b)**.

Results of the experimental studies of geometry optimization of the output backward-facing step forming nozzle (figure 1) providing the stable outflow of lengthy quasi-laminar jet from plasma torch with IEI [3] are presented in review papers [1, 2]. This type of jet flows is of interest for treatment and spraying of low-thermal-conduction oxide powders, and also post-treatment, including submelting, of coatings non-critical to oxidation.

In figure 2 the optical photo of argon-nitrogen plasma jet is presented, outflowing in the air atmosphere under the following conditions: arc current I = 200 A; voltage U = 200 V; main working gas – mixture of argon and nitrogen (G_{Ar} = 0.25 g/s, G_{N2} = 0.43 g/s); argon flow rate for anode protection – G_{Ar} = 0.07 g/s; D_1 = 9 mm; D_2 = 10 mm; D_3 = 18 mm.

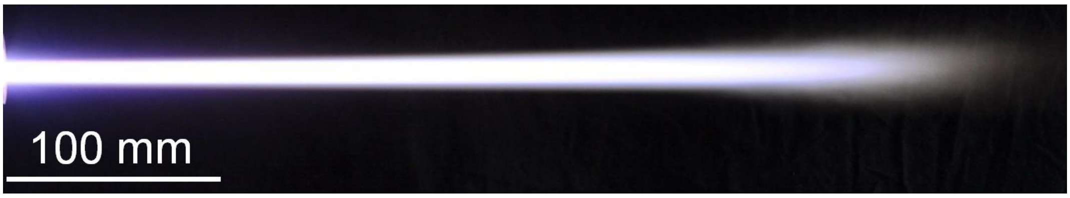


Figure 2. Optical photo of argon-nitrogen quasi-laminar plasma jet.

However, the use of the forming nozzle in the form of the backward-facing step (figure 1) leads to ejection of air from the surrounding atmosphere in it.

Figure 3 illustrates the distributions of oxygen volume concentration in three control sections of the jet L = 100, 150 and 200 mm. From the presented results it can be seen that on jet axis the minimum volume content of oxygen is in the section L = 100 mm which usually meets the spraying distance, is not less than 5 % and grows with the distance from plasma torch nozzle exit.

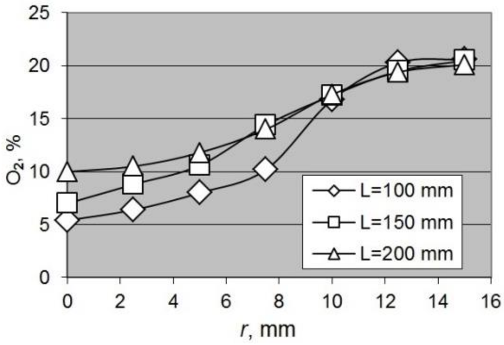
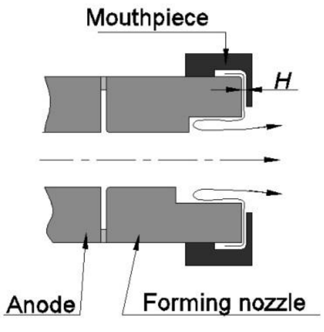


Figure 3. Distribution of the oxygen volume concentration in control sections of the jet.



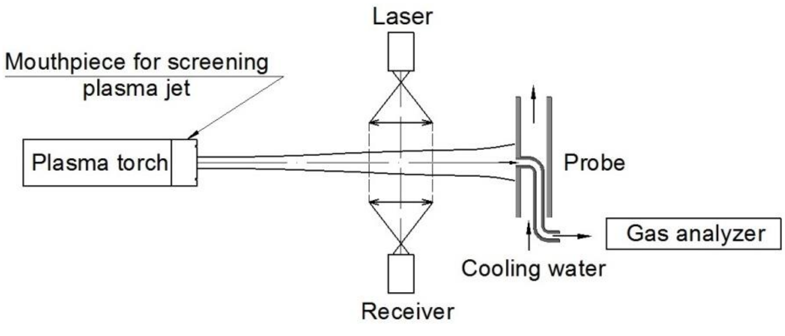


Figure 4. Schematic diagram of plasma jet shielding.

Figure 5. Scheme of the experimental setup for diagnostics of plasma jet.

In order to decrease the ejection of air in the backward-facing step from the surrounding atmosphere, and, therefore, the content of oxygen in plasma jet, a nozzle mouthpiece was developed, schematically presented in figure 4, and investigations on its optimization using the experimental setup were conducted which schematic diagram is presented in figure 5.

The nozzle mouthpiece for radial-annular slot shielding of plasma jet is schematically shown in figure 4 and includes a receiver with distributor in which, for the constant feed of the protective (shielding) gas, on the one side 12 holes with diameter of 1 mm were evenly and circumferentially made, and on the other side – 8 tangential grooves 3 mm wide and 0.15 mm deep for the homogeneous filling with shielding gas (argon) of circular slit of the given width H. As a probe for local sampling of gas the water-cooled tube with the external diameter of 3 mm was used in which the tube with the internal diameter of 0.5 mm was soldered. Sampling and analysis of the gas sample was provided by means of BONAIR TEST 1-6 gas analyzer at distances z = 100, 125, 150, 175 and 200 mm on jet axis at the operating conditions of plasma torch stated above.

When carrying out experiments the following parameters varied: width of the circular slit (H = 1 and 2 mm) and flow rate of shielding gas (argon). At the same time, flow rate of argon was set so that for slits H = 1 mm wide and H = 2 mm the weight-average flow rates of radial-converging jets for corresponding flow rates of argon were identical. In figure 6 the experimental data characterizing the distributions of oxygen volume concentration along the axis of plasma jets depending on width of slit and flow rate of shielding argon are submitted. As it can be seen from the submitted data, the use of shielding nozzle mouthpiece with radially converging near-wall protective argon jet allows, all other things being equal, to significantly reduce (by almost two times) the oxygen concentration on the axis of plasma jet for the control section L = 100 mm in comparison with its outflow without nozzle mouthpiece. It should be noted that the offered method of plasma jet protection, in comparison with commonly used axial schemes [4, 5], etc. does not demand increased flow rate of the shielding gas which leads to excessive turbulization of the jet with increase in distance from plasma torch nozzle exit.

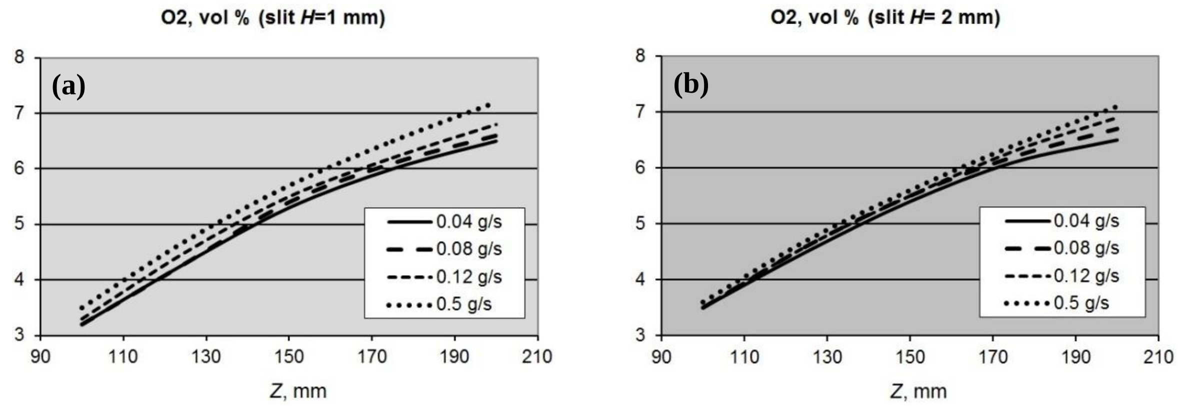
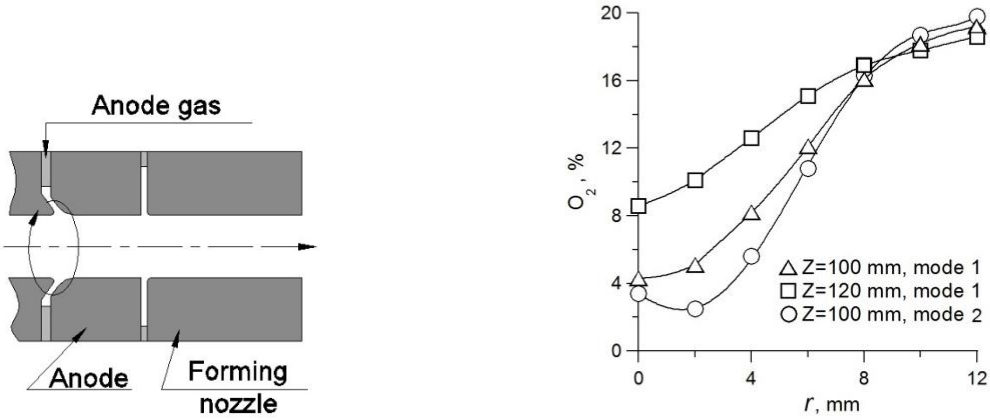


Figure 6. Distribution of oxygen concentration along the jet axis when using the shielding mouthpieces with the width of slit H =1 and 2 mm, **(a)** and **(b)**, respectively.

The considered above method of shielding of the plasma jet, outflowing at low Reynolds number from torch with IEI having forming nozzle in the form of backward-facing step, is of prime interest for surface treatment, including melting of coatings. For treatment of powder materials and plasma spraying, the use of the backward-facing step with ejection of gas from surrounding atmosphere is very problematic as at input of powder under the forming nozzle exit section the ejected gas will entrain the small particles of sprayed or treated powder in the backward-facing step that will lead to their unwanted deposition on the walls of forming nozzle.

In this regard, we have studied the second method of jet protection based on axisymmetric slit input of shielding gas (argon) into the channel of plasma torch just in front of the anode (figure 7(a)) behind which the forming nozzle with cylindrical or diffuser channel is installed.

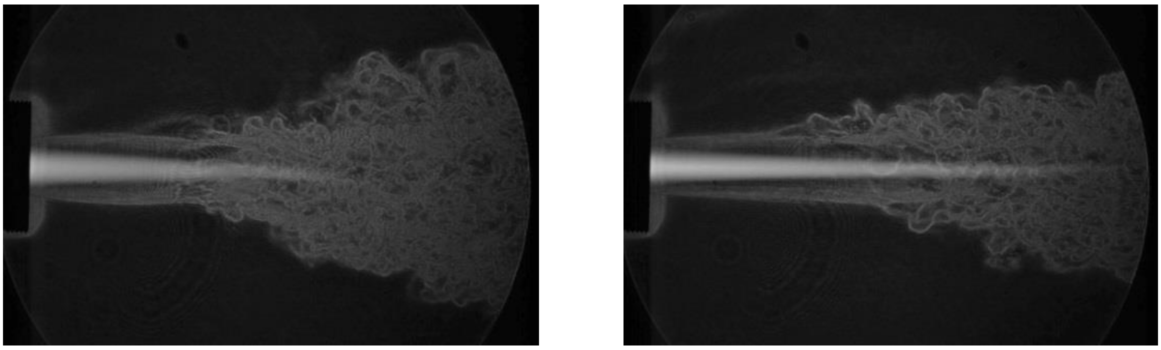
However, unlike rather lengthy argon-nitrogen or nitrogen quasi-laminar plasma jets outflowing at low Reynolds numbers, it’s quite problematic to achieve a lengthy laminar argon-helium jet without admixture of oxygen from the surrounding atmosphere.



(a) **(b)**

Figure 7. The scheme of axisymmetric slit input of shielding gas in front of anode **(a)** and distributions of oxygen concentration in the control sections of plasma jet **(b)**.

Investigations of behavior of argon-helium plasma jet were conducted at fixed composition and flow rate of the main working gas – mixture of argon and helium (G_{Ar} = 0.4 g/s, G_{He} = 0.2 g/s), but with variable flow rate of shielding argon supplied in front of the anode (figure 7(a)). The analysis of oxygen content in argon-helium jet shows (figure 7(b)) that at the flow rate of shielding argon G_{Ar} = 0.14 g/s (mode 1, Reynolds number Re ~ 150) the minimum oxygen content in the control section z = 100 mm is 4.1 %, and with increase in distance up to 120 mm it increases on the jet axis by almost two times. The corresponding measurements for argon-helium jet outflowing at the flow rate of shielding argon G_{Ar} = 0.42 g/s (mode 2) revealed feature connected with the minimum oxygen content observed not on the jet axis, but rather in zone with radius r ~ 2 mm where oxygen volume concentration equals 2.5 % (figure 7(b)).



(a) **(b)**

Figure 8. Shadowgraphs of flow in plasma jets depending on flow rate of shielding argon.

The analysis of the flow pattern in plasma jets outflowing from torch were carried out using the shadow device with adaptive visualizing transparency for recording phase heterogeneities [6]. The diameter of the observed area provided by the device was 120 mm and the frame exposure is 3 μs with image recording frequency of seven frames per second. Shadowgraphs of plasma jets at two flow rates of the argon supplied in front of the anode are provided in figure 8: G_{Ar} = 0.14 g/s (figure 8(a)) and G_{Ar} = 0.42 g/s (figure 8(b)).

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