# EXPERIMENTAL INVESTIGATIONS ON PARTICLES HEATING IN TRANSFERRED DC “TUBULAR” PLASMA ARC

## ЕКСПЕРИМЕНТАЛНО ИЗСЛЕДВАНЕ НА НАГРЯВАНЕТО НА ЧАСТИЦИ В ПРЕХВЪРЛЕНА ПОСТОЯННОТОКОВА ПЛАЗМЕНА ДЪГА “ТРЪБА”

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**Abstract:** *The particles heating parameters in a transferred DC “tubular” plasma arc are investigated. The plasma torch construction offers a combination between a hollow graphite cathode and a copper water-cooled nozzle. A special feature of this design is that the plasma gases are introduced from the two sides (interior and exterior) of the “tubular” graphite cathode, i.e. the gases are bilaterally blown and the plasma arc reaches “tubular” configuration. Such an organization of the plasma arc enables the introduction of the powder charges through the hollow graphite cathode for processing in plasma-surrounded volume. The influence of particle mass flow rate on the arc parameters for current 250 A and 100 mm plasma arc length is investigated. The optimal parameters ensuring a maximal plasma torch power are determined.*
***KEYWORDS**: TRANSFERRED DC “TUBULAR” PLASMA ARC, PARTICLE HEATING*

### 1. Introduction

The degree of particle heating in a plasma arc volume between the cathode and anode has importance for the efficient performance of plasma metallurgy processes taking into account the essentially differing requirements to specific technologies. For this purpose it is necessary to define the electrical, geometrical and gas dynamic parameters by which stable burning, a well established “tubular” plasma arc is achieved. By means of variation of the parameters the optimal values which ensure the particles technological heating, typical of every process can be defined.

In order to accumulate experimental data, experiments for investigation of particle heating from carbonyl-iron with sizes -0,1+0,063 mm were carried out in a “tubular” plasma arc volume.

A special plasma torch design with hollow graphite cathode generating a transferred DC tubular plasma arc is used [1-7]. Replacing of the W-cathode by a hollow graphite one through which the processed material is introduced is specific of the arc plasma torch design.

The plasma gas-argon is blown from both sides of a hollow cathode into the space between it and the water cooled nozzle and through the cathode hole. This ensures obtaining of a tubular transferred plasma arc.

The experiments were carried out at equal flow velocity of the two plasma gases [7], as the mass flow rate of the introduced material is changed. A basic purpose of the investigation is to check the degree of particle heating depending on the mass flow rate of the introduced material and the velocities of plasma gas while the current and plasma arc length are constant.

### 2. *INVESTIGATION OF DISPERSE MATERIAL HEATING IN THE PLASMA ARC VOLUME*

The defining of the degree of particle heating is a very difficult task because it is impossible to measure the arc temperature directly. That imposes development of a new indirect method. In the heating of molten metal at constant plasma arc parameters, the melting temperature increases smoothly by a parabolic dependence. If additional solid material falls into the melt, the temperature remains approximately constant for a definite time interval due to compensation of the latent heat of particle fusion.

If liquid material falls in the crucible this effect isn’t observed. Only the rate of temperature growth of the melt is changed.

The described method consists essentially in measurement of the carbonyl-iron melt temperature using thermocouple WRe-5/20, located on the axis of the crucible at 5 mm from the melt, while simultaneously feeding of powder material at a definite mass flow rate [7].

The experiments are carried out in 4 series with different mass flow rate of the powder material: 5, 20, 30 и 50 g/min at two velocities of the plasma gas - $v_1$=$v_2$=12 m/s and $v_1$=$v_2$=20 m/s. Initially 200 g pure iron powder (produced by carbonyl method) is loaded in the crucible and the heating starts with by means of plasma arc at constant work parameters I=250 A, $L_{arc}$=100 mm, $V_2$=1500 l/h, $V_1$=550 l/h ($v_1$=$v_2$=12 m/s). Simultaneously time-temperature curve of the process in the interval 1530÷ 41610°C is recorded (curve 1, Fig.1.)

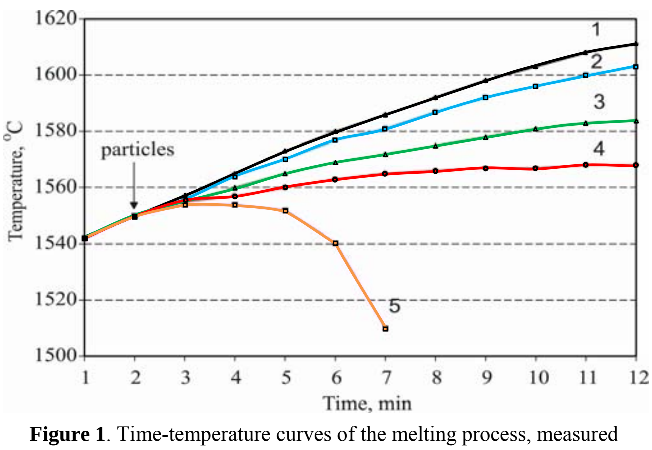


**Figure 1**. Time-temperature curves of the melting process, measured without powder material passing – curve 1 and with powder material passing – curve 2 – 5 g/min,3 – 20 g/min, 4 – 30 g/min and 5 – 50 g/min.

The next experiments are carried out when, after melting of the pure iron in the crucible at temperature of 1550 C, through the plasma arc, feeding of pure iron powder with sizes -0,1+0,063 mm is started with mass consumption 5, 20, 30 and 50 g/min, (respectively curves 2, 3, 4 and 5 in Fig. 1). We observe that at curves 2 and 3 (5 and 20 g/min) the character of temperature increase is similar to that of curve 1 as we notice slowing down of its growth rate in the time.

While in the standard curve 1 the temperature increases in 10 min from 1550°C to 1610°C, in curves 2 and 3 in the same time the temperature reaches levels 1602°C and 1583°C respectively. We have the reason to make a conclusion that the slowing down of the temperature-increase rate is at the expense of the arc energy, consumed on heating and melting of the particles. They fall liquid in the melt. For curve 4 (30 g/min) we observe that the temperature gradually increases from 1550°C to 1565°C in 8 min, and after that it remains practically constant. This shows that the particles for this mass consumption heat up to a temperature near the melting point. The arc energy is sufficient only to compensate for the latent heat. We have a reason to make the conclusion that this is the limit mass flow rate, where the particles heat in the arc over the melting point.

The last curve 5 (Fig.1) supports the upper conclusion. At consumption 50 g/min, we observe sharp decrease of the melt temperature in the crucible; approximately 5 min after the start of material feeding the melt crystallizes, while the fed material starts to accumulate in solid state in the crucible. That shows that the particles fed to the arc volume heat to a temperature considerably below their melting point.

The plasma arc voltage changes for different mass consumptions of powder material in Fig. 2. ($v_1$=$v_2$=12 m/s) correspond to the picture in Fig. 1. The investigation was carried out for parameters I=250 A, $L_{arc}$=100 mm, while after the charge melts at a temperature of 1550°C powder material is fed for two minutes at different, increasing mass flow rates.

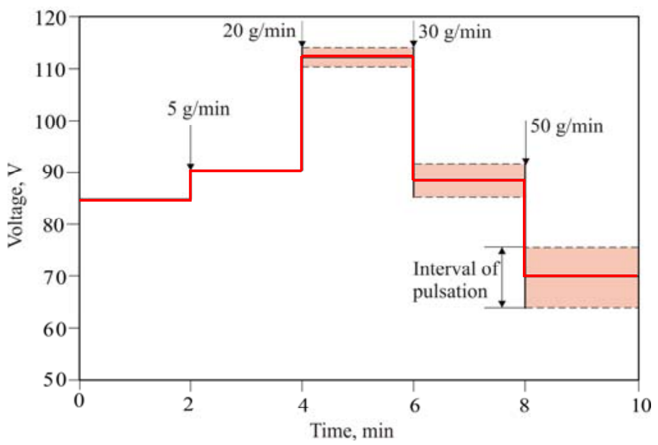


**Figure 2**. The plasma arc voltage changes for different mass consumption of powder material fraction -0,1+0,063 mm by I=250 A, $L_{arc}$=100 mm, $v_1$=$v_2$=12 m/s

**Fig. 2** shows that for consumption 5 g/min the arc voltage is increased by 5÷6 V, which is due to more intense cooling, caused by the fed material, respectively to increase of the thinning ("wasting away" of the "tubular" plasma arc wall), and the increase of its resistance. The next increase of powder material quantity to 20 g/min increases the voltage by about 10 V. We observe voltage pulsations in boundaries 3÷4 V which is probably due to the electrical fault effect of the arc caused by the metallic powder particles. Increasing of the material quantity to 30 g/min is due to a comparatively sharp decrease of the voltage to about 90 V. The pulsating is intensified because of the higher concentration of electricity conductive particles in the arc. The described effect is most pronounced at maximum mass flow rate of the fed material - 50 g/min. In this case the average voltage falls to about 70 V, while pulsation levels change strongly with time. Since the current remains constant, the plasma arc power also varies with the change of voltage **(Fig. 3).**

An analogous investigation has been carried out at plasma gas velocity 20 m/s **(Fig.4)**. The figure shows that the particles cannot be heated up to melting temperature and fall in the crucible in solid state.

In curves 2 and 3 (Fig. 4.) illustrating mass consumption 5 and 20 g/min, we observe that the particles are heated up to temperature near the melting point.

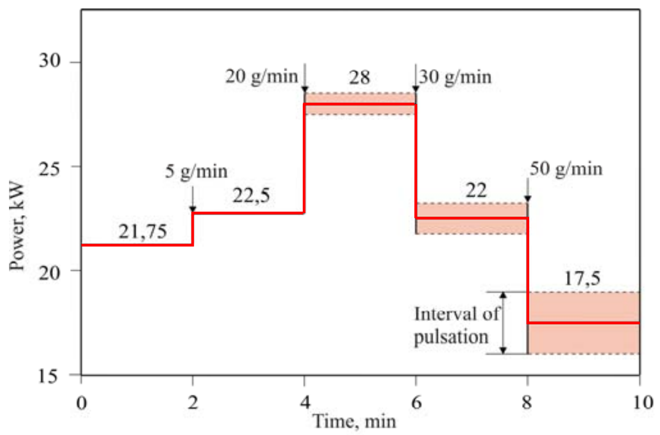


**Figure 3.** The plasma arc power changes for different mass consumption of powder material fraction -0,1+0,063 mm by I=250 A, $L_{arc}$=100 mm, $v_1$=$v_2$=12 m/s

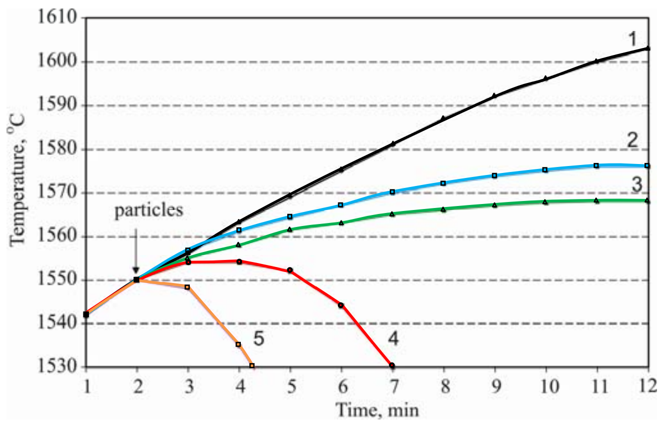


**Figure 4.** Time-temperature curves of the melting process, measured without powder material passing – curve 1 and with powder material passing – curve 2 – 5 g/min,
3 – 20 g/min, 4 – 30 g/min, 5 – 50 g/min, $v_1$=$v_2$=20 m/s.

At mass consumption of powder material of 30 and 50 g/min - curves 4 and 5 (Fig.4.) the melt crystallizes accordingly at the seventh and the fourth minute from the start of material feeding.

At higher velocity of the two gases the measured voltage (Fig. 5), respectively the power (Fig. 6) is increased insignificantly. In spite of that due to the higher velocity, at which the particles cross the high temperature arc zone, they fail to heat to the melting temperature.

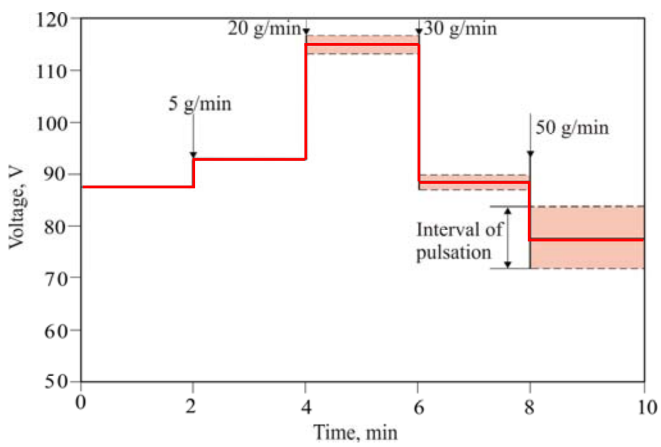


**Figure 5.** The plasma arc voltage changes for different mass consumption of powder material fraction -0,1+0,063 mm by I=250 A, $L_{arc}$=100 mm, $v_1$=$v_2$=20 m/s

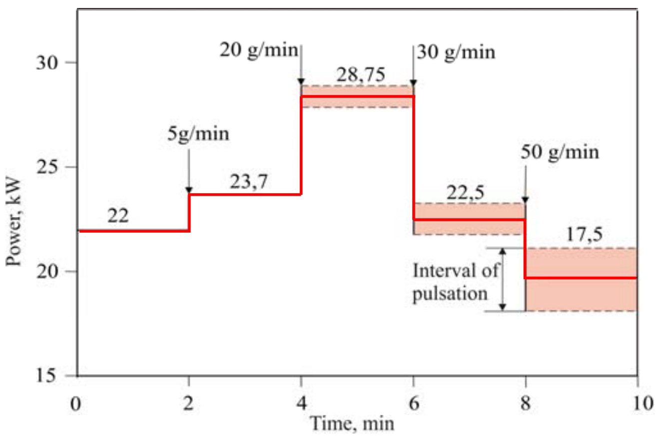


**Figure 6.** The plasma arc power changes for different mass consumption of powder material fraction -0,1+0,063 mm by I=250 A, $L_{arc}$=100 mm, $v_1$=$v_2$=20 m/s

Experiments demonstrate that at constant optimal parameters of the plasma arc, one way of regulating the particle heating, depending on the process requirements is to change of the specific quantity of the fed material.

### 3. *CONCLUSIONS*

With the existing geometrical sizes of the nozzle and of the plasma torch cathode, arc length 100 mm and current 250 A, mass flow rate of plasma gas $V_1$=550 l/h and $V_2$=1500 l/h, ($v_1$=$v_2$=12 m/s), 20 g/min is the optimal quantity of the heating material (carbonyl-iron with particle sizes -0,1+0,063 mm). At this specific mass flow rate a maximum average electrical power of the plasma torch 28 kW is achieved.

By varying of the plasma arc power – increasing of the current or arc length in definite admissible limits, it is possible also to influence the degree of disperse material heating.

The obtained experimental data are used for verification of the developed mathematical model of dispersed material heating in a "tubular" plasma arc.

### 4. *REFERENCES*


[1] Bengtsson e., Widell B., The Chemistry of the ELRED Process, Iron and steelmaking, Vol.8, No10, October, 1981, pp.30-34

[2] Barza N.A., Curr T.R. and Maske K.U., The Application of Thermal Plasma Technology to Large Scale Pyrometallurgical Processes, Extraction Metallurgy'85, Institute of Mining and Metallurgy, London, June, 1985, pp.709-740

[3] Barza N.A., The Development of Large-Scale Thermal-Plasma Systems, J.S.Afr.Inst.Min.Metall., Vol.86, No8, August 1986, pp.317-333

[4] Barza N.A., Curr T.R. and Jones R.T., Metallurgy of Open-Bath Plasma Processes, Pure & Appl.Chem., Vol.62, No9, 1990, pp.1761-1772

[5] Mihovsky M., Avramov A., Tzonev Tz., Metalurgia, (1994) №1-2, p.71-77.

[6] Mihovsky M., Tzonev Tz., 1st International Congress of Science and Technology of Ironmaking, ISIJ, Sendai, Japan, (1994), p. 621-626.

[7] Angelova V., Mihovsky M., Petkov V., Mihailov E., Technological Parameters of Transferred DC "Tubular" Plasma Arc (International Virtual journal "Machines, Technologies, Materials" Issue 10-11, p. 9-10)