DISTRIBUTION OF THE TEMPERATURE ON THE LIQUID METAL SURFACE IN THE FURNACE WITH TRANSFERRED PLASMA ARC

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Abstract
The article presents a methodology for the measurement of temperature on the liquid metal surface in the conditions of melting in the plasma furnace using an optical pyrometer. The effect of plasma radiation on the values of measured temperature has been discussed. It has been found that the one-colour temperature is directly proportional to the arc current. The real temperature of the metal surface is mainly influenced by the level of the metal bath heating. The anode spot temperature has been found to fall within the range from 1700 to 2300°C in the experimental conditions.

Introduction
The knowledge of the liquid metal surface temperature during heating with transferred plasma is indispensable for the description of thermodynamic phenomena and chemical reactions occurring at the liquid metal - slag - gas (plasma) interface. The most important investigations of the metal surface temperature are presented in papers [1; 2; 3]. The authors of this paper regard the results of those research works as incorrect because of too high values of temperatures [4].

The present study reports the results obtained from tests carried out in a laboratory plasma furnace at the Extraction Department of the Technical University of Częstochowa.

1. Methodology of measurements
Temperature measurements were taken by means the two-colour optical pyrometer (Integrated Ratio Pyrometer MR1F) by RAYTECK with a measurement range of 1000 – 3000°C. Measurements were executed after switching off the plasma arc (an electrical system operating the shutter) and in the presence of the plasma beam (using an optical filter that modifies the radiation characteristics) [4]. This measurement method has three major advantages from the point of view of experimental methodology, namely [5]:
- short measurement (exposure) time - below 10 ms (practically, in the order of magnitudes of 5·10^{-3} s);
- dual output:
  - analogue output (4 - 20 mA) - the values of one temperature whose changes are consistent with the exposure time (recording by means of the analog/digital PC-LabCard);
  - digital output - computerized recording, using the serial port, of the following temperatures: two-colour temperature, two single-colour temperatures, and wideband power (WBP; 0.75 + 1.1 im) and narrow-band power (NBP; 0.95 + 1.1 im) of radiation, with transmission rate below 20 Hz;
- capability of the digital selection of radiation parameters, such as emissivity and slope.
The thermal state of the ceramic crucible was monitored by means of five thermocouples, whose signals were recorded on the second computer, along with the electrical parameters of the plasma arc.
The plasma furnace with ceramic crucible has been described in numerous publications [6; 7]. Its basic parameters are as follows: power - 100 kW DC; working pressure - 0.005 + 0.5 MPa; plasma-generating gas - Ar.

The tests were conducted for electrolytic nickel (99.98 % Ni), Fe-C (1.6 %) and stainless steel with the metal mass being 20 kg.

![Diagram of the measuring system](image)

**Fig. 1** The scheme of the measuring system.

2. Results of experiments

Figure 2 shows variations of the metal surface temperature after switching off the plasma arc, as recorded via the digital channel. In this case, it was noticed that the temperature of the surface reached a thermal equilibrium with the crucible after 15 second. The value of this two-colour temperature can be a measure of the thermal state of the working chamber $T_{c, av}$ (steady state of the thermal transfer).

During the measurements using plasma (by the optical filter – analog recording method), the oscillation of the temperature could be observed, resulting from the pulsation of the plasma (Fig. 3). The pulsation was present during the measurements of the ceramic crucible surface, too. Thus, the optical measurement of the metal surface temperature was impossible. The temperature shown in Fig. 3 ($T_2$) is not real, as the optical filter modifies the radiation.

![Temperature graph](image)

**Fig. 3** Two- and one-coloured temperatures.
Fig. 2 The variations of the temperature after switching off the plasma arc (digital recording – no optical filter; Ni)

![Graph showing temperature variations over time](image)

Fig. 3 The variations of the two-colour temperature in the presence of a plasma arc (analog recording with the optical filter)

![Graph showing temperature variations](image)

3. Analysis of results

The monochromatic temperature is directly proportional to the current of the plasma arc [3] and this is confirmed in our experiment (Fig. 4). The one-colour wide band temperature T1W is not a measure of the metal surface temperature, because T1W is highly dependent on the plasma radiation.

It can be found from the measurements that the two-colour temperature has no physical meaning – the calculated values of T2 temperatures are considerably higher than 10000 °C. The real temperature of the metal surface can be established only by the calculation of temperature at the moment of switching off the arc current. In this instance one should take into account the time of disappearance of the plasma in the furnace space. Thus calculated temperature is influenced mainly by the level of heating of the metal baths and of the furnace working space (Fig. 5).

![Graph showing relationship between arc current and maximum temperature](image)

Fig. 4 The effect of the plasma arc current on the one-colour wide band temperature

![Graph showing relationship between arc current and T1W temperature](image)
temperature T1W (analog recording)

![Graph showing temperature values]

Fig. 5. The effect of the level of heating of the metal baths on the metal surface temperature in the anode spot area.

4. Summary

On the basis of the investigations, of which only part is reported in the present article, it can be concluded that the surface temperature is influenced mainly by the type of metal being melted and by the level of heating of the metal baths and the furnace working space. The effects of the electrical parameters of the plasma arc, the flow rate of the plasma-generating gas, and the pressure within the furnace, on the other hand, are much lesser [2].

The results, which are presented in papers [1; 2; 3] are of little reliability because the measurements have been made by means of monochromatic radiation (with the wavelength 0.65 μm).

In summary of the above, it can be stated that the liquid metal surface temperature in the anode spot falls within the range 1700–2300°C in the experimental conditions.

References

[1] Laktionov A.W., Stomakhin A.Ja., Grigorian W.A., Izv. WUZ, CzernMetall., 1979, No 5, s. 72-77