HEAT TRANSFER BETWEEN A CERAMIC PLATE AND THE FLAME OF A MOVING PLASMOTRON

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The procedure and results for determining the amount of heat entering a plate with the motion of a plasmotron with different velocities are presented.

The processes involved in the transfer of heat from a plasma jet to a barrier have been examined in greatest detail for the case when the plasmotron and the barrier are stationary relative to one another [1, 2]. There are no data in the literature on heat transfer between the surface of the body and the flame of a moving plasmotron. Processes involving polishing of parts made of different materials with the motion of a flame or arc along the surface being treated are, however, encountered in practice [3].

This paper is concerned with developing a procedure and investigating heat flows in a ceramic plate from the flame of a powerful moving plasmotron. Figure 1 shows the scheme of the experimental setup. The plasmotron 1 with the "hot" graphite electrodes operates on AC current and air. The barrier 2 is made of silica brick. The plasmotron is heated up within 60-70 sec in a position such that the jet is pointing into region 3. Copper sensors 4 with a diameter of 0.016 m and a length of 0.04 m are placed flush with the barrier at different distances R from the center line. The center line lies in the plane of motion of the plasmotron axis. In order to measure the temperature of the sensors, Chromel—Alumel thermocouples 5 are placed in the sensors at a distance of 0.01 m from the heated face. The indications of the thermocouples are recorded by a KSP4 instrument. The dependence of the amount of heat entering the plate on the velocity of the plasmotron w, on the distance between the cutoff of the plasmotron nozzle and the barrier s, on the diameter of the rod electrode d, and on other factors were determined in the experiments. The gap between the electrodes in this case remained constant and equal to 0.005 m, and the external diameter of the ring electrode was 0.1 m. In most experiments the current strength was $I = 1600$ A, the voltage on the electrodes was $U = 80$ V, the flow rate of air was 7.5 m^3/h, the insertion depth of the core electrode was $h = 0$, the diameter of the rod was $d = 0.065$ m and its length was $l = 0.12$ m, and the distance $s = 0.02$ m.

We determined the amount of heat entering the ceramic plate by two methods. In the first method we placed the sensors into the brickwork without the thermocouples. After the plasmotron was heated up, we switched on the movement mechanism. The plasmotron, moving along the wall with a certain velocity, melted the wall and heated the sensors. After the plasmotron passed the sensors, we switched off the movement mechanism and the current sources. We moved the plasmotron away from the wall and placed the sensors into the calorimeter 6 (Fig. 1). We calculated the amount of heat absorbed by the sensor from the flame with the

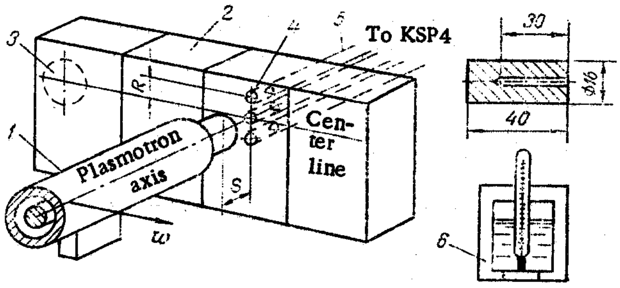

Fig. 1. Diagram of the experimental setup.

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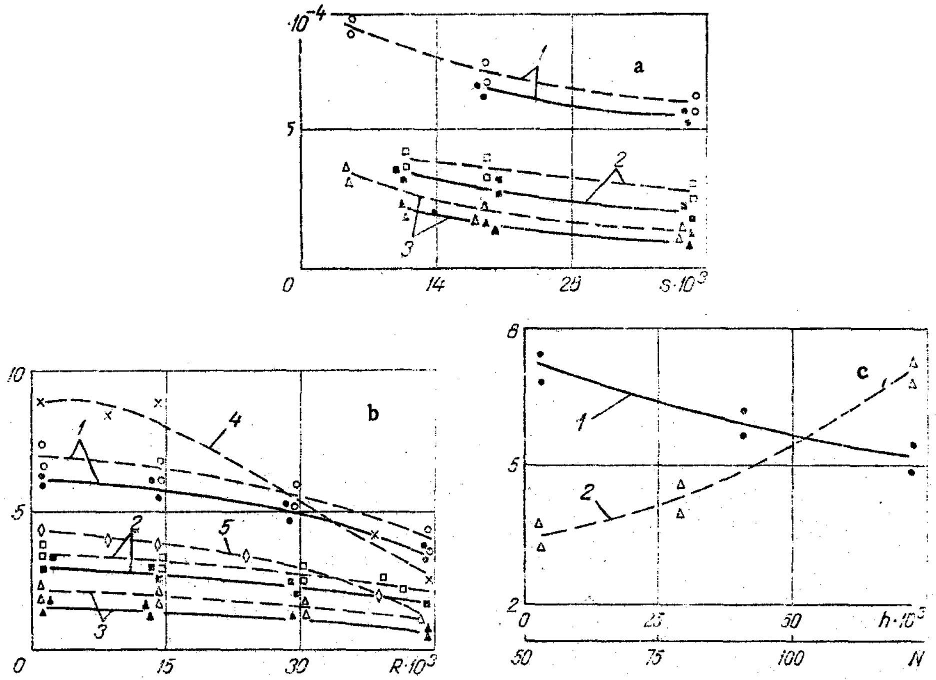

Fig. 2. Dependence of the amount of heat q (kJ/m^2) entering the plate on the distance s (m) between the plasmotron and the barrier (a), on the distance R(m) up to the center line (b), on the insertion depth h (m) of the inner electrode and power N (kW) of the plasmotron (c): (a) 1) w = 0.015; 2) 0.03; 3) 0.05 m/sec; R = 0; (b) 1) w = 0.015; 2) 0.03; 3) 0.05 m/sec; 4) d = 0.045 m; w = 0.015 m/sec; 5) d = 0.045 m; w = 0.03 m/sec; (c) 1) q = f(h); d = 0.052 m; 2) q = f(N); R = 0; w = 0.015 m/sec. The dark circles correspond to the first method for measuring q and the light circles correspond to the second method.

help of the equation of heat balance

$$c_s m_s t_1 + (c_c m_c + c_w m_w + c_t m_t) t_0 = (c_s m_s + c_c m_c + c_w m_w + c_t m_t) t_2, \tag{1}$$

where t_1 is the temperature of the sensor after heating by the plasmotron; t_0 is the initial temperature; and t_2 is the temperature after the sensor was placed in the calorimeter.

The heat obtained by the thermometer or, in other words, the correction for the error introduced by the thermometer $Q_t = c_{tmt}(t_2 - t_0)$ was insignificant under our conditions, because the temperature t_2 changes by less than 1°C when the thermometer is inserted into the calorimeter. Based on what was said above, from (1) we find the amount of heat entering the sensor through unit area of the end face over the time of its interaction with the flame:

$$q = \frac{Q}{F} = \frac{1}{F}(c_s m_s + c_c m_c + c_w m_w)(t_2 - t_0),$$

where $Q = c_d m_d (t_1 - t_0)$.

In the experiments we used a calorimeter with mass of 0.162 kg, a sensor with a mass of 0.071 kg, and water with a mass of 0.075 kg. The experimental data are presented in Fig. 2 by the continuous lines.

In determining the amount of heat entering the plate according to the second method, the measurements of the temperature with the help of the thermocouple show that under the action of the moving flame the temperature of the sensor at first increases rapidly, reaches a maximum, and then (after the flame has passed) slowly decreases as a result of removal of heat from the sensor into the plate and the surrounding medium. The amount of heat obtained by the sensor from the plasmotron flame is determined by the equation

$$q = \frac{c_d m_d}{F}(t_m - t_0),$$

where t_m is the maximum temperature of the sensor in the experiment. The results of determination of q by the second method are shown in the figures by the dashed lines.

It is evident from Fig. 2a that the amount of heat entering into the plate is affected by the distance s from the plate to the cutoff of the nozzle and the velocity w of the plasmotron. As the distance increases, the amount of heat q decreases, due to dissipation of heat into the surrounding medium. In order to maintain a constant current, in these experiments the air flow rate was decreased from 10 to 2 m^3/h as s varied from 0.005 to 0.04 m. As the velocity of the plasmotron increased, the amount of heat in the plate q likewise decreased, since the time of interaction of the flame with the heated surface decreases. For low velocities (w = 0.015 m/sec) and short distances (s = 0.005-0.01 m) the heat flows reach magnitudes at which the end face of the sensors melts.

The amount of heat obtained by a sensor, as for a stationary plasmotron [1], depends on the distance up to the flame axis R. As R increases, the amount of heat in the sensor decreases (Fig. 2b). The nature of the distribution of q with respect to R is also affected by the diameter of the core electrode. As the diameter of the electrode decreases, the nonuniformity of the distribution of the specific amount of heat over the width of the melted band increases (curves 4 and 5).

Figure 2c shows the dependences of the amount of heat entering the plate on the power of the plasmotron and the insertion depth of the electrode h. The decrease in q with increasing h is caused by the increasing distance between the heat source (electric arc) and the heated surface.

The lower values of q, obtained according to the first method, are explained by losses of heat as the sensor is extracted from the ceramic plate and transferred into the calorimeter. The data obtained by these investigations should be viewed as approximate. The actual amounts of heat entering the ceramic plate from the flame of the moving plasmotron differ from the measured values due to the different nature of the materials of the sensor and of the plate and to melting and evaporation of the ceramic. Based on the magnitudes of q found and under the assumption that the width of the plasma flame is ~ 0.1 m, the average (over the width) heat flux densities (kW/cm^2) can be calculated for different velocities of the plasmotron and compared with data from other investigations for a stationary plasmotron.

Information on the removal of and melting-through of the surface layer of the silica brickwork is also of interest. For large values $q = (5\text{-}9)\cdot 10^4$ kJ/m^2 and high velocities 0.03-0.015 m/sec, intense melting, evaporation, and removal of a layer of material 2-4 mm thick occur. The comparatively low values $q = (0.2\text{-}2)\cdot 10^4$ kJ/m^2 with velocities 0.8-0.05 m/sec correspond to melting of a surface layer from 0.1 to 1 mm deep.

NOTATION

R, distance between the sensor and the axis of the plasmotron; s, distance between the plasmotron and the barrier; d, diameter of the cone electrode; l, length of the electrode; w, velocity of the plasmotron; c, specific heat capacity; m, mass; t, temperature; q, amount of heat referred to unit area; and F, area of the end face of the sensor. Indices: s, sensor; c, calorimeter; w, water; t, thermometer.

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