Technology of treatment of building materials with the plasma torch

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Abstract. The paper describes the solutions of the building materials heat conduction problems – heating source power and size definition based on temperature measurements on a material surface and on layers, heating source characteristics and surface temperature identification by temperature measurements on a treated area. The basic problem of the building concrete block heating by mobile Gauss type thermal source are addressed. As a result there are given formulae for an estimation of the plasmatron useful power and maximal temperature on the depth $z \geq 1$ mm with accuracy enough for a practical appliance. Also values of the main technological parameters during the treatment are recommended and the technology of concrete block finish is shown.

1. Introduction
Today electric arc treatment of materials is widely used in various industries: metallurgy, engineering, construction, chemical industry, etc. [1-3]

Most plasma devices make the low-temperature plasma by gas heating in the electric arc [1, 2]. For high-speed plasma (more 90 m/sec) flow and high consumptions linear blowed arc plasmatrons are usually used. In such plasma torches the high powers are implemented at high voltages and relatively low currents (up to 1000 A). In this case, the plasma flame has a small size. The extended sources of heat are required for ensuring the necessary productivity in some practical cases (e.g., melting of construction details; plasma treatment of dielectric materials). These sources have the form of a single pressed arc or a wide plasma flame. They are characterized by high enthalpy and low-speed of gas flow (< 50 m/s).

The thermal processes of heating of material by means of high-concentrated energy flows are investigated mainly for metals [3]. Plasma heating of ceramic and building materials is investigated much less. This determined the aim of comprehensive theoretical and experimental research of heat transfer processes during electric arc treatment of materials.

In this article we investigated heat processes in the surface layer of the concrete slab during plasma treatment.

2. Theoretical statements
As we know the heat treatment of silicate materials with a powerful heat source occurs usually at high speed, and is characterized by great values of Peclet number. Consequently, if we analyze the stationary problem of a temperature field in a moving slab at the coordinates associated with the surface heat source with intensity $q(x)$, we focus on two main factors: the speed of movement of the
heat source and the heat conductivity on depth of the heated material. Thus, we have the following simplified stationary problem:

$$
\frac{\partial T}{\partial x} + \frac{x}{\partial x^2} = 0
$$

(1)

$$
T(x) = 0, -\lambda \frac{\partial T}{\partial z} = q(x)
$$

(2)

where

$$
q(x) = q_0e^{-\frac{x^2}{\rho^2}}
$$

The solution of this problem is:

$$
T = \frac{q_0}{\lambda} \sqrt{\frac{\pi}{\nu}}e^{\frac{x^2}{\nu}}
$$

(3)

On condition that: $$\frac{X}{\nu} > 0$$ . The surface temperature is easily determined from equation (3) when $$z = 0$$.

$$
T_s(x) = \frac{q_0}{\lambda} \sqrt{\frac{\pi}{\nu}}e^{\frac{X^2}{\nu}}
$$

(4)

After a detailed analysis of the equation (3) we have two asymptotics for maximal temperature by depth $$z$$: linear asymptotic and hyperbolic asymptotic.

Linear asymptotic ($$Dp < 1$$):

$$
T_{MAX}(z) = A - B \cdot z
$$

(5)

where

$$
A = \frac{q_0}{\lambda} \sqrt{\frac{\pi}{\nu}}e^{\frac{X^2}{\rho^2}}, B = \frac{q_0}{\lambda e^{0.25}}
$$

Hyperbolic asymptotic ($$Dp > 1$$):

$$
T_{MAX}(z) = \frac{C}{z}
$$

(6)

where

$$
C = \frac{q_0X'X_0}{\lambda \nu} e^{\frac{2}{\nu}}
$$

$$
Dp$$-criterion:

$$
Dp = \frac{z}{2} \sqrt{\frac{\nu}{X'X_0}}
$$

$$Dp$$-criterion allows to delimit the linear asymptotic (near-surface layer) from the hyperbolic asymptotic (technologically significant layer). If the plasma torch with a characteristic size $$r_0 = 0.05$$ m moves along the surface of the concrete slab at a speed of $$v = 0.3$$ m/s, then from the equality the
$D_p = 1$ we obtain $z \approx 0.5$ mm. I.e., at a depth of $z < 0.5$ mm the maximal temperature decreases linearly, and at a depth of $z > 0.5$ mm the maximal temperature decreases hyperbolically.

We can use these temperature asymptotics for solving an inverse problem - definition of power and the characteristic size of the heat source on measurements of temperature at different depths of the heated material.

3. Research results
As input parameters we use a thermal characteristics of concrete [4-6]: $\lambda = 1.45$ W/(m°C); $\chi = 0.8 \cdot 10^{-4}$ m²/s; $T_{MEL} = 1700$ °C; $v = 0.3$ m/s. The melting temperature of the concrete approximately coincides with a surface temperature $T_S = T_{MEL}$ (at $z = 0$). Then from equation (5) we obtain the equality:

$$\frac{q_0}{\chi} \sqrt{\frac{\pi \rho_0}{2v e^{0.5}}} = 1700$$ (7)

We will find a value ($C$) in a technologically significant layer ($z > 0.5$ mm) after processing data with least squares method for hyperbolic function (7)

$$C = \frac{q_0 \zeta_0}{\chi v} \sqrt{\frac{2}{e}} = 0.4582$$ (8)

Power of the Gaussian surface heat source is determined by the expression:

$$P = q_0 \zeta_0^2$$

Then, we find the power and the characteristic size of the heat source from the integrated solutions of equations (7) and (8): $P \approx 42.7$ kW, $r_0 \approx 0.051$ m.

Next we consider another inverse problem: finding the temperature on the surface $T_S$ of the heated slabs from the available data $T_{MAX}(z)$. In this case it is necessary to use more complicated asymptotic instead of a hyperbolic asymptotic (6), namely:

$$T_{MAX}(z) = C \left(1 - \frac{D}{z^2} + \frac{6 D^2}{z^4}\right)$$ (9)

where

$$C = \frac{q_0 \zeta_0}{\chi v} \sqrt{\frac{2}{e}}, D = \sqrt{2} \frac{\zeta_0}{v}$$

Then we use nonlinear least squares method and find values of the parameters: $C = 0.4260$ m°C, $D = 1.48 \cdot 10^{-7}$ m².

We obtain the following equation:

$$\begin{align*}
\frac{q_0 \zeta_0}{\chi v} \sqrt{\frac{2}{e}} &= 0.427 \\
\sqrt{2} \frac{\zeta_0}{v} &= 1.48 \cdot 10^{-7}
\end{align*}$$ (10)

From this system we determine the characteristic size of the source $r_0 \approx 0.04$ m and its power $P \approx 40$ kW. We use the linear asymptotics (5) at $z = 0$ to calculate the temperature on the surface. The result is $T_S \approx 1750$ °C.

The obtained surface temperature well combined with the melting temperature of the concrete (1700 °C). The values of $r_0$ and of $P$ are lower about 10 – 15 % than the real characteristics of the plasma torch. If we consider the extreme sensitivity of inverse problems to inaccuracies of input data, the increase in the number of unknown parameters from two to three under the same experimental
initial data, this result can be considered quite satisfactory. We can recommend values of the main technological parameters, with taking into account the results of the research to ensure the quality of the treated surface and the stable mode of operation of the plasma torch in the treatment of concrete slabs: $G = (1500 \pm 2500)$ kg/s; $I = (1200 \pm 1500)$ A; $U = (70 \pm 100)$ V; $H = (0.01 \pm 0.03)$ m; $v = (0.2 \pm 0.3)$ m/s.

Temperature research for the heated surface of the concrete slab shows us that the temperature is not dangerous for the material and does not exceed 142 °C. The Figure 1 shows the heating curve during continuous heating of concrete slab. Each heating passage was shifted on half of the width of the plasma flame.

![Figure 1. The heating curve during continuous heating of concrete slab.](image)

4. Conclusion

We have received the technology for treatment of concrete slabs by plasma surface reflow method, that is based on the research results which include the selection of the base material, decorative blends, salts, powders, methods of forming products, the determination of plasma treatment conditions, test the properties of the coatings, composition of the technology process of the plasma surface reflow of building materials, etc.

It is necessary to highlight most important aspects of the technology which was obtained during the research and allow to achieve a high quality of products treatment.

It is desirable to use light quartz sand with a particle size of 3-5 mm during plasma treatment as a placeholder subsurface layer. It is also possible to use crushed white glasses with the same particle size in admixture with sand of usual composition (main placeholders). With this composition of subsurface layer the staining properties of a pigment will be better, and striation from the treatment plasma torch will be less noticeable.

The material of building product does not overheat due to high speed of plasma treatment (plasma torch speed 0.2 – 0.3 m/s). It allows us to exclude a special heat insulating layer.

It is preferable to make the treatment of product «face-up» during plasma treatment. In this case the surface is well cleaned and does not have grease residues. If the product is treated «face-down», the surface will have densified structure. It is not so easy to clean such a surface and include residues of grease that make the surface black during the treatment.
References

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