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MODELING OF THE TEMPERATURE FIELD ON A THERMODIFFUSION-GALVANIZING LINE

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Results of mathematical modeling of the temperature field in the working volume of a thermodiffusion-galvanizing unit on the basis of the assumptions of convective heat exchange are given.

Thermodiffusion zinc coatings produced in powders have significant advantages over zinc electroplates and hot-dip galvanized coatings for physicomechanical properties and corrosion resistance [1].

The development of new production lines for thermodiffusion galvanizing of long-dimension products [2, 3] has made it possible to create thermodiffusion-galvanizing areas; selection of technological parameters involves the necessity of carrying out a large amount of experimental work. In this connection, mathematical modeling of the entire process of galvanizing and, in particular, modeling of the process of change of the temperature field in the working volume of a thermodiffusion-galvanizing unit are a topical problem.

Let us consider the formulation of the problem. A container filled with zinc powder and product slowly rotates and heats up, traversing the first, second, and third furnaces. It is assumed that the temperature on the exterior surface of the container is equal to the furnace temperature. As the container rotates, zinc is mixed and it "washes" the interior container surface and the product, which reflects on the process of heat transfer. Mathematical modeling of the process of heating of the system container–product assumes that we have convective heat exchange between the product and the powder and between the powder and the container.

The incomplete filling of the container with powder is considered. In the general case we must take into account the heat capacity of the container itself. Let us denote the container temperature by $T_3(t)$. For this case the system of equations has the form

$$\frac{dT_1}{dt} = a\,(T_2 - T_1)\,; \tag{1}$$

$$\frac{dT_2}{dt} = b\,(T_3 - T_2) + c\,(T_1 - T_2)\,; \tag{2}$$

$$\frac{dT_3}{dt} = k\,(T_2 - T_3) + p\,(T_\mathrm{w} - T_3)\,; \tag{3}$$

$$T_i\big|_{t=0} = T_0\,, \quad i = 1, 2, 3\,; \tag{4}$$

$$a = \frac{\alpha_1 S_1}{m_1 c_1}\,; \quad b = \frac{\alpha_2 S_2}{m_2 c_2}\,; \quad c = \frac{\alpha_1 S_1}{m_2 c_2}\,; \quad k = \frac{\alpha_2 S_2}{m_3 c_3}\,; \quad p = \frac{\alpha_3 S_3}{m_3 c_3}\,.$$

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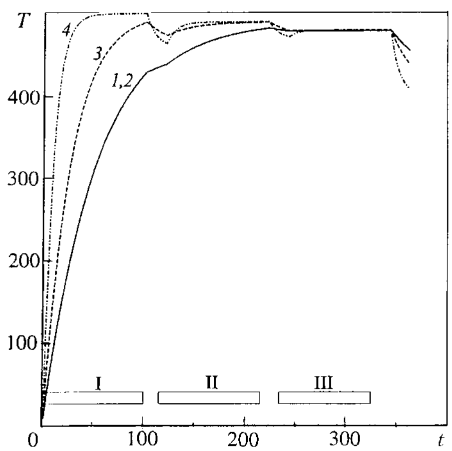

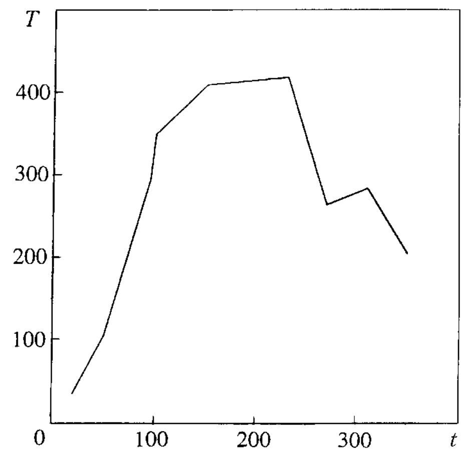

Fig. 1. Temperature of the product vs. time of stay in the furnaces (velocity of motion of the container is 4 m/h): 1) the area of the container–powder contact is 3 m^2 and that of the product–powder contact is 3 m^2; 2) 3 and 18 m^2; 3) 6 and 3 m^2; 4) 18 and 3 m^2; I–III, furnaces. T, ^{o}C; t, min.

Fig. 2. Product temperature vs. time of traversal of the furnace by the container (in the container are zinc powder and the product; the container velocity is 4 m/h).

Figure 1 gives the characteristic properties of the formation of a temperature field in the working volume of the unit in the approximation of the model of convective heat exchange for different production conditions. In the calculations, we used the following data: mass of the product 500 kg, specific heat of the product material 461 J/(kg·K), specific heat of the powder 840 J/(kg·K), mass of the powder 250 and 500 kg, surface of contact of the powder with the product 2.5 to 8.5 m^2, surface of contact of the powder with the container 2 to 8 m^2, initial temperature 20^{o}C, furnace length 3 m, distance between the furnaces 0.5 m, temperature of the first furnace 500^{o}C, temperature between the first and second furnaces 100^{o}C, temperature of the second furnace 490^{o}C, temperature between the second and third furnaces 100^{o}, temperature of the third furnace 480^{o}, and temperature after the third furnace 20^{o}. The calculation results are presented in the form of the time dependence of the temperature for different areas of contact of the container and the product with the zinc powder and different masses of the powder. Curve 1 in Fig. 1 has been obtained by selecting the coefficients of heat exchange at the powder–product (α_1) and powder–container (α_2) boundaries. For the above conditions they are equal to 0.01 and 20 W/(m^2·K) respectively. It is seen in the figure that, first, the product takes the temperature of the container (furnace) for a certain time and not instantaneously and, second, the largest influence on the rate of heating of the product is exerted by the area of the powder–container contact (curves 2 and 3); the change in the area of the powder–container contact virtually exerts no influence on the rate of heating. The most rapid heating of the product (curve 3) over a short period of time is attained due to the larger area of contact of the powder with the container, which corresponds to the smaller diameter of the container. An increase in the powder mass leads to a reduction in the rate of heating (curve 2), despite the slight increase in the area of the powder–container contact. The results of experimental investigations are given in Fig. 2. The model of convective heat exchange satisfactorily describes the temperature field in the working volume of a unit for thermodiffusion galvanizing of products and it can be used in calculating the thermal regime of the unit and selecting the optimum regimes of operation.

NOTATION

α_1, α_2, and α_3, coefficients of heat exchange between, respectively, the powder and the billet, the powder and the container, and the interior container surface and the ambient medium, W/(m^2·K); m_1, m_2, and m_3, mass of the product, the powder, and the container, kg; c_1, c_2, and c_3, specific heats of the powder, the product, and the container, J/(kg·K); T_0, initial temperature of the powder and the product, K; T_w, temperature on the external boundary of the container, K; T_1 and T_2, temperatures of the product and powder, K; S_1, S_2, and S_3, areas of contacts of the product surface with the powder and the powder with the container and area of the exterior surface of the container, m^2. Subscript: w, wall.

REFERENCES

1. E. V. Proskurkin, *Handbook of Galvanizing* [in Russian], Moscow (1988).
2. Patent No. 2023971, published November 30, 1994.
3. Patent No. 2156830, published September 27, 2000.