EFFECT OF TEMPERATURE AND SURFACE CONDITION ON THE INTEGRAL EMITTANCE OF NICKEL AND GERMAN SILVER

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Air heating of nickel at 800-1000°C involves considerable oxidation of its surface and increase in the integral emissive power. Most intensive air heating of nickel takes place in ovens at temperatures of 1000°C. This regime may presumably be regarded optimum for metal heating in ovens.

To analyze and calculate complex heat exchange in reheating furnaces, information is needed on the radiation characteristics of the metals being heated. In furnaces with indirect radiant roof heating, the integral blackness of the metal significantly affects the rate of its heating. The greater its value, the more rapid the increase in the temperature of the ingot. In this connection, in designing furnaces and selecting optimum modes for heating metal ingots, information is needed on the effect of temperature, type of treatment, and atmosphere on the integral emittance of semifinished products heated to 800-1250°C before rolling.

We studied the effect of temperature, surface condition, and the composition of the atmosphere on the integral emittance of specimens of NPA-1 nickel and German silver cut from ingots teemed at the Orsk OTsM plant. The integral emittance of the specimens in the normal direction (ε_T) was determined by the radiation method on an improved unit described in [1].

Specimens 25-30 mm in diameter and 2-4 mm thick were placed in the test chamber. The heating mode for the specimens corresponded to commercial practice (ingots heated for 1 h 20 min to ∿ 1200°C before rolling). The specimens were heated in stages of 20-50°C each up to the melting point. Before starting the measurements and during the tests, the unit was calibrated in accordance with measurements of a polished tungsten surface — a metrological standard [2]. Special attention was given during the tests to the method of accounting for the temperature gradient between the specimen surface and thermocouple junctions. To this end, we used the method of elementary thermal balances to calculate the temperature distribution in different sections of the specimen on a BÉSM-6 computer. Also, in conducting the tests the thermocouple readings were calibrated according to the melting points of aluminum, copper, nickel, and iron. The resulting information was taken into account in computing ε_T.

The absolute values of integral emittance were computed by two methods: the method of equal temperatures, and the method of equal radiation flows. The value of ε_T was computed by the former method using the relation

$$\varepsilon_T = \frac{U}{U_0}\varepsilon_T^0, \tag{1}$$

where U and U_0 represent thermocouple signals for the specimen and standard, respectively; ε_T^0 is the integral blackness of tungsten.

In the method of equal flows

$$\varepsilon_T = \frac{T^4 - T_k^4}{T_0^4 - T_k^4}\varepsilon_T^0, \tag{2}$$

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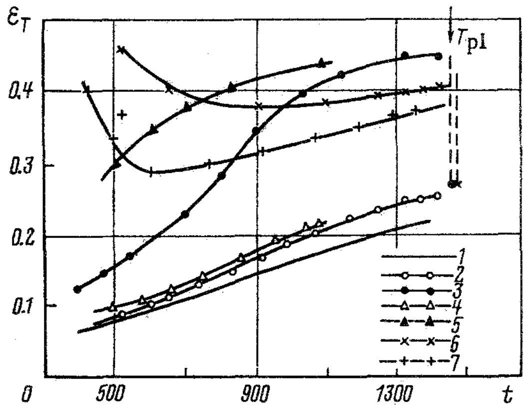

Fig. 1. Temperature dependence of ε_T for nickel and German silver: 1) polished nickel, data of [2]; 2, 3) milled nickel heated in helium and air, respectively; 4, 5) milled German silver heated in helium and air; 6, 7) oxidized nickel heated in air and helium;

where T and T_0 are, respectively, the temperature of the specimen and standard at which the radiation from their surfaces is the same; T_k is the temperature of the thermocouple.

The main contribution to the error in the determination of ε_T is made by the systematic error. In accordance with Eq. (1), the latter may be written as follows:

$$\frac{\delta\varepsilon_T}{\varepsilon_T} = \pm\left[\frac{\delta U}{U} + \frac{\delta U_0}{U_0} + \frac{\delta\varepsilon_T^0}{\varepsilon_T^0}\right]. \tag{3}$$

Since $U \sim T^{4,5}$ for metals, Eq. (3) converts to

$$\frac{\delta\varepsilon_T}{\varepsilon_T} = \pm\left[\frac{4.5\delta T}{T} + \frac{4.5\delta T}{T} + \frac{\delta\varepsilon_T^0}{\varepsilon_T^0}\right] = \pm\left[\frac{9\delta T}{T} + \frac{\delta\varepsilon_T^0}{\varepsilon_T^0}\right]. \tag{4}$$

Thus, most of the measurement error is due to the error in determining specimen temperature. Careful calibration of the thermocouples shows that δT does not exceed 10°. At 1500°K, this error amounts to 6%. The relative error in the determination of ε_T^0 for tungsten was $\sim$ 2% [2]. Thus, the total systematic error in the determination of ε_T at 1500°K does not exceed 8%. However, it rapidly increases with decreasing temperature. The random error in the determination of ε_T was considerably smaller ($\sim$ 1-2%). Thus, the resulting error in measurement of ε_T at 1500°K is 9%, but may reach 20% or more at low temperatures $\sim$ 500°K.

An analysis shows that the method of equal flows, with a linear thermocouple characteristic, makes almost no reduction in the error of the ε_T determination. Other factors act to lower the accuracy of ε_T values: reflection from the chamber walls and inside elements of the unit, absorption of part of the radiation by intervening media, etc. These factors may make a contribution of the order of 1% to the error in ε_T measurement.

Figure 1 shows the results of measurements of the integral emittance of oxidized and milled specimens of nickel and German silver heated in air and helium. Also shown are data from the literature on measurement of the integral emittance of polished nickel in an inert atmosphere [2].

It follows from Fig. 1 that the ε_T of milled nickel heated in helium and characterized by a substantial degree of surface roughness only slightly (by 3-10%) exceeds the blackness coefficient of polished nickel. With heating of such specimens in air to 800-1000°C, intensive oxidation of the surface begins and is accompanied by an increase in integral blackness. Nickel specimens heated in helium and in air are characterized by a degree of blackness exceeding by 1.5-2 times the value for a polished surface (curve 3). Moreover, it follows from the results shown that the melting of nickel in air is accompanied by a brief decrease in integral blackness due to destruction of the oxide film. With further heating, an oxide film is again formed on the surface of the molten metal.

German silver specimens heated in air are characterized by higher (2-3 times) values of radiation characteristics throughout the investigated temperature range compared to heating in a helium atmosphere.

The nonmonotonic nature of the ε_T curves for the oxidized specimens may be explained by the fact that the thin oxide film on the specimen surface is destroyed in the temperature range 500-1000°C and the values of ε_T drop accordingly (curves 6 and 7). The oxide film is destroyed at a lower temperature in helium.

For the investigated milled specimens of nickel and German silver heated in air, the radiation characteristics increase with temperature due to the formation of a strong oxide film (curves 3 and 5). Here, the blackness coefficients of these specimens at $t \geqslant 1000$°C correspond to the ε_T of the oxidized specimens.

Thus, heating of nickel in air at 800-1250°C is accompanied by substantial oxidation of its surface and an increase in integral blackness. Consequently, ingots are heated most rapidly in air with furnace temperatures exceeding 1000°C. This mode is evidently optimal for heating ingots in reheat furnaces and may be recommended for practical application.

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HEATING OF PLATES WITH AN ABSORPTION COEFFICIENT DEPENDENT ON TEMPERATURE AND RADIATION FLOW

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Plate heating with a temperature-dependent absorption coefficient is investigated. It is shown that with increasing power density of an incident flux the kinetics of temperature growth undergoes pronounced qualitative changes. The threshold power density value at which plate heating is accompanied by darkening as well as the darkening time are found. Calculation results are in good agreement with experimental data.

The elements of optical systems are now often subject to the effects of laser radiation flows. Semiconductor materials have found wide use in applied optics. One property of such materials is a clearly expressed dependence of the absorption coefficient on temperature. Several studies have been devoted to the heating of semiconductor plates by optical radiation. Results of empirical studies have been published in [1], e.g., and theoretical results have been presented in [2-5]. The dependence of the absorption coefficient on temperature was approximated in these works by either an exponential curve or a polynomial. It must be noted that in [2-4] the distribution function for the heat sources, determined by the Bouguer–Lambert law, was linearized. Such an approach leads to results that are less than fully satisfactory. In particular, this formulation of the problem permits an unlimited increase

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