MEASUREMENTS OF THE SPECTRAL EMISSIVITY OF STEEL IN A GASEOUS REDUCTION ATMOSPHERE

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INTRODUCTION

The present paper presents a description and exemplary results of laboratory measurements of the normal spectral emissivity of a steel sheet carried out within the temperature range from 400°C to 800°C. The heating process was carried out in a protective gaseous atmosphere. The results of the measurements were used to work out recommendations concerning the adjustment of pyrometers operating in the control system of a furnace[1]. The test stand is to be seen in Fig. 1. While the sample was heated up (or cooled down), its temperature was measured by means of a thermocouple and a pyrometer. Selected samples were measured twice, repeating the heating up and cooling of the sample.

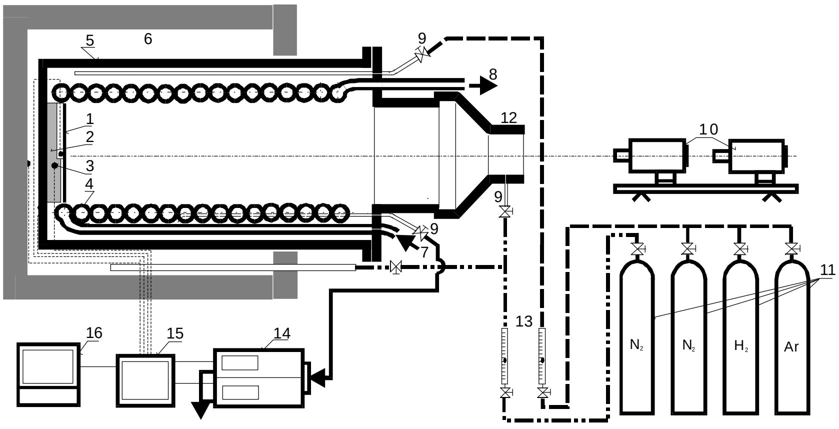

Fig.1. Scheme of the measurement stand; 1- sample of steel, 2-bottom plate, 3-thermocouples, 4-water jacket, 5-measurement capsule, 6-furnace chamber, 7,8-water outlet/inlet, 9-inlet/outlet of protection gas, 10-pyrometers, 11-protection gases, 12-eyehole, 13-rotameters, 14-gas analysers, 15-data logger, 16-computer

DETERMINATION OF THE MONOCHROMATIC EMISSIVITY AS A FUNCTION OF TEMPERATURE AND WAVELENGTH

The real emissivity of the sample was calculated making use of the following relation:

$$\varepsilon_r = \varepsilon_p \frac{\int_{\lambda_1}^{\lambda_2} e_{c\lambda}(T_p)\ \mathrm{d}\lambda}{\int_{\lambda_1}^{\lambda_2} e_{c\lambda}(T_r)\ \mathrm{d}\lambda} \tag{1}$$

where: $\varepsilon_r, \varepsilon_p$ - real emissivity of the sample and the emissivity adjusted on the pyrometer, $e_{c\lambda}(T_p)$, $e_{c\lambda}(T_r)$ - spectral densities of the emission[2] at the temperature of pyrometer T_p and the real temperature T_r, λ_1, λ_2 - spectral range of the pyrometer. Exemplary values of the calculated real emissivity of the investigated sample have been presented in Fig.2.

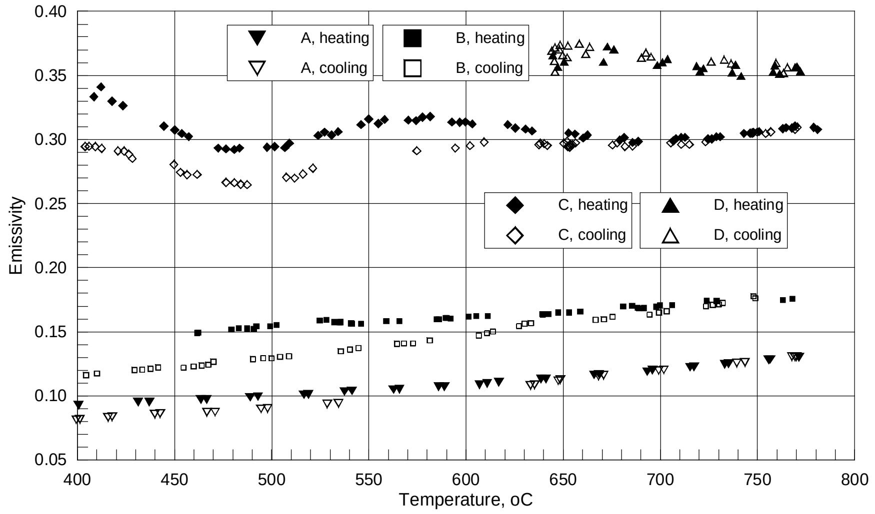

Fig.2. Exemplary measurement results of emissivity for various wavelength of thermal radiation: A-11 µm, B-5.1 µm, C-1.6 µm, D-1.0 µm

Basing on these results, approximated relations were determined for each wavelength represented by the applied pyrometers in the form of polynominals expressing the emissivity of the sample as a function of the temperature T:

$$\varepsilon_r = a_0 + a_1 T + a_2 T^2 + a_3 T^3 + \dots \qquad \textbf{(2)}$$

where: a - coefficients. In order to determine isothermal changes of the emissivity as a function of the wavelength, through the points situated along the mentioned polynominal curves, curves were passed expressing changes of the monochromatic emissivities as a function of the wavelength. The theoretical equation describing the spectral emissivity of an ideally smooth surface of metals takes the following form[3]:

$$\varepsilon'_{\lambda,n} = \frac{b_1}{\sqrt{\lambda}} \qquad \textbf{(3)}$$

where: b_1 - constant coefficient, λ - wavelength of thermal radiation. The emissivity of a real surface is higher than that of an ideally smooth surface. One of the main reasons for this is the roughness of the surface. The apparent increase of the emissivity of any surface caused by covering its dimples may be expressed by the well-known formula[2]:

$$\varepsilon_{\lambda,n} = \frac{\varepsilon'_{\lambda,n}}{1-(1-\varepsilon'_{\lambda,n})\varphi} \qquad \textbf{(4)}$$

where: $\varepsilon_{\lambda,n}$ - spectral emissivity of the real surface, φ - configuration factor taking into account the self-radiation of the surface due to its roughness. After transformations of the relations (3, 4) a general relationship (5) was obtained, expressing the real spectral emissivity of the surface as a function of the wavelength:

$$\varepsilon_{\lambda,n} = \frac{1}{b_2\sqrt{\lambda} + b_3} \qquad \textbf{(5)}$$

where: b_2, b_3 - constant coefficients. Applying the obtained polynominal relations, for successive values of temperature within the range from 400°C to 850°C the values of the coefficients b_2, b_3 in equation (5) could be determined. Fig. 3 shows exemplary curves determined in this way.

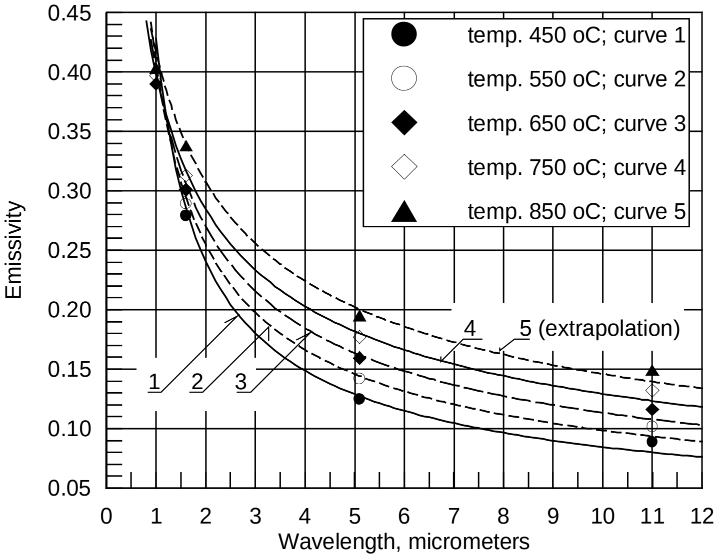

Fig.3. Exemplary curves presenting an influence of wavelength on spectral emissivity in various temperatures

FINAL REMARKS

According to literature, there is in the case of metals a characteristic wavelength, the so called X-point[3], at which the monochromatic emissivity does not depend on temperature. If the wavelength of radiation is shorter than in the X-point, the monochromatic emissivity decreases with the rise of temperature, and if the wavelength of radiation is longer, the emissivity grows with temperature. In the case of iron (steel) the X-point occurs at the wavelength of 1 μm[3]. The obtained results of measurements confirm this phenomenon, Fig. 3. In the course of taking measurements it was observed that the emissivity measured during the heating of the sample differs from that measured while it was cooled down. The most probable reason of this phenomenon is the removal of the residue of iron oxides by means of reducing them with the hydrogen from the protective gas, these iron oxides having been left in the microroughness of the surface of the sample although it had been cleaned. The results of measurements taken in the course of cooling the sample may be considered to be most representative.

REFERENCES

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Stainless-steel low-emissivity coatings reduce absorptance of infrared radiation into a glass shield. The use of optical materials improves the efficiency in passive cooling and energy efficient windows.Â The shield absorbs some of the coming energy from the sun and the atmosphere, reflects back a part in the space and transmits the rest toward the absorber. The absorber emits thermal radiation toward the shield which is partially reflected and absorbed by the absorber (radiator).Â The spectral transmittance and reflectance of the optimal thickness of stainless steel thin film (150 nm) deposited on borosilicate glass substrate (3 mm) (side 2) are shown in Figure 5. From spectral reflectance, we can see the position of the critical point structure at 0.41 eV (0.32 Î¼m) [22] . This gaseous halo radiates in X-ray wavelengths, and as it radiatively cools, it has the capacity to form stars. However, large cooling flows accom-panied by prodigious star formation are not observed: the predominant stellar populations at the centers of the most massive halos are old and red, and X-ray measurements in-dicate a lack of cool gas compared to the level expected from the cooling (e.g., Oegerle et al.Â Sensitive millimeter-wave observations have the poten-tial to reveal the Sunyaev-Zelâ€™dovich effect of the hot gas associated with radio AGN. The Sunyaev-Zelâ€™dovich (SZ) effect is a spectral distortion in the cosmic microwave back-ground (CMB) that occurs when CMB photons inverse-Compton scatter off of the hot ionized gas associated with dark matter halos.