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Regular article

Emissivity model of steel 430 during the growth of oxide layer at 800–1100 K and 1.5 μm

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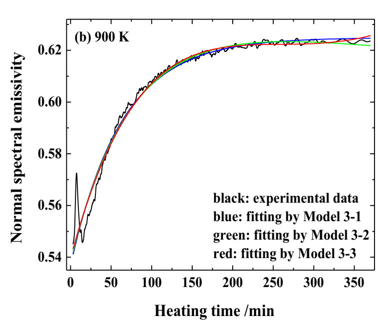
HIGHLIGHTS

- Eleven emissivity models were evaluated.
- Uncertainties in the temperature were approximately 4.1–10.7 K.
- Variation in the emissivity with heating time was discussed at a certain temperature.
- Variation in the emissivity with temperature was evaluated at a certain heating time.
- Spectral emissivity as a function of heating time temperature was determined.

GRAPHICAL ABSTRACT

This work studied the variation in the spectral emissivity of steel 430 with growth of oxide layer at 1.5 μm over a temperature range 800–1100 K. In the experiment, the temperature was measured by the two thermocouples. The variation of spectral emissivity with growth of oxide layer was evaluated at a certain temperature. Altogether 11 emissivity models were evaluated. The conclusion was gained that the more the number of the parameters used in the models was, the better the fitting accuracy became. On the whole, all the PEE models, the four-parameter LEE model and the five-parameter PFE, PLE and LEE models could be used to well fit this kind of variation. The variation in the spectral emissivity with temperature was determined at a certain thickness of oxide film. Almost all the models studied here could be used to accurately evaluate it. The approximate models of spectral emissivity as a function of temperature and oxide-layer thickness were proposed. The strong oscillations of spectral emissivity were observed, which were affirmed to arise from the interference effect between the two radiations coming from the oxide layer and from the substrate. The temperature uncertainty generated only by the surface oxidization was approximately 4.1–10.7 K in this experiment.
Experimental and fitting spectral emissivity curves of steel 430 versus the heating time at the temperatures of 820 and 900 K.



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ABSTRACT

This work studied the variation in spectral emissivity with growth of oxide layer at the different temperatures. For this reason, we measured the normal spectral emissivity during the growth of oxide layer on the sample surface at a wavelength of 1.5 μm over a temperature range 800–1100 K. In the experiment, the temperature was measured by the two thermocouples, which were symmetrically welded onto the front surface of specimens. The average of their readings was regarded as the true temperature. The detector should be perpendicular to the specimen surface as accurately as possible. The variation in spectral emissivity with growth of oxide layer was evaluated at a certain temperature. Altogether 11 emissivity models were evaluated. The conclusion was gained that the more

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the number of parameters used in the models was, the better the fitting accuracy became. On the whole, all the PEE models, the four-parameter LEE model and the five-parameter PFE, PLE and LEE models could be employed to well fit this kind of variation. The variation in spectral emissivity with temperature was determined at a certain thickness of oxide film. Almost all the models studied in this paper could be used to accurately evaluate this variation. The approximate models of spectral emissivity as a function of temperature and oxide-layer thickness were proposed. The strong oscillations of spectral emissivity were observed, which were affirmed to arise from the interference effect between the two radiations stemming from the oxide layer and from the substrate. The uncertainties in the temperature of steel 430 generated only by the surface oxidization were approximately 4.1–10.7 K in this experiment.

1. Introduction

Steel is a very representative alloy used in each field of modern industry. Most processes in the steel production (e.g., forging, extrusion, and rolling) are highly temperature-dependent, and precise determination of temperature has a strong bearing on both process control and final product quality. For example, in order to achieve the desired microstructure and product quality, accurate temperature measurements are necessary during the melting, casting, heating of billets, and profile pressing. As we know, these processes suffer from very highly-elevated temperatures (usually above 800 K) and are completely exposed in air. More importantly, most processes preclude direct physical contact of a temperature probe with the steel surface, especially during profile pressing for parts in transit. That is, pyrometers are required to accurately measure the temperature.

Spectral emissivity is an essential parameter employed in one-color pyrometers. A large number of experimental spectral emissivity data can be currently available in the literature for various steels. However, spectral emissivity of steels is very difficult to be determined exactly since it depends on a number of factors such as composition of steels, temperature, wavelength, angle, as well as type and shape of the surface [1]. Even if the difficulties noted here could be overcome completely, there are still some additional problems with this parameter during the temperature measurement with one-color pyrometers, because the oxidization status on the steel surface is always changing from time to time, in particular for steels being heated at an elevated temperature in air. Therefore, it is important to clarify the spectral emissivity behavior of steels for which the temperature is measured, prior to applications of one-color pyrometers [2], in particular the effect of surface oxidization on spectral emissivity at very high temperatures.

There have been many experiments [2–13] in the past years of more than ten, in which the effect of surface oxidization on spectral emissivity of various steels was evaluated. For example, Kobayashi et al. [3] in 1999 measured the time variations of spectral emissivity of cold-rolled steel at wavelengths ranging from 0.55 to 5.3 μm and temperatures ranging from 780 to 1200 °C. Furukawa and Iuchi [2] in 2000 investigated the effect of surface oxidization on spectral emissivity of cold-rolled steel at wavelengths of 1.35, 1.55 and 2.2 μm and at temperatures of 823 and 873 K. Iuchi [4] in 2003 modeled the spectral emissivity of cold-rolled steel during the growth of oxide layer. Campo et al. [5] in 2006 measured the spectral emissivity of Armco iron at some temperatures over a wide wavelength range and evaluated the effect of surface oxidization on spectral emissivity. Pujana et al. [6] in 2007 investigated the time variations of spectral emissivity of 42CrMo4 steel. Wen et al. [7–9] studied the effect of surface oxidization on spectral emissivity of several kinds of steels at some wavelengths and temperatures. And Reschab et al. [10] in 2011 presented the spectral emissivity at melting and in the liquid state of highly alloyed steel HS2-9-1-8 at a wavelength of 684.5 nm.

Summarizing the experimental results [2–10] noted above, we find that they had several common features. All the measurements [2–10] studied only the variation in spectral emissivity with growth of oxide film at different wavelengths and different temperatures. None modeled the spectral emissivity as a function of oxide layer and/or temperature. Our previous experimental work [11,12] showed that the effect of surface oxidization on the spectral emissivity of steels was approximately governed by a same rule at a certain temperature. However, the models obtained in previous work [11,12] were complex and lack of reliability because too many parameters were used.

In this paper, we select steel 430 specimens as target. The reason is that no experimental spectral emissivity has been reported for this steel in the literature up to now, let alone modeling the spectral emissivity as a function of growth of oxide layer and/or temperature. In addition, it is not known how many temperature measurement uncertainties could be generated only by the surface oxidization at a certain wavelength. This problem should be solved because we must clarify the measurement accuracy when we employ one-color pyrometers to measure the temperature of this kind of steel.

Seemingly, it might be straight forward to determine the variation of emissivity with growth of oxide-layer thickness. However, it is very hard to determine the congruent relationship between the emissivity and the thickness of oxide layer, since the surface oxidization takes place anytime and anywhere, in particular at an elevated temperature. That is, it is very hard to ensure that the thickness of oxide film on the sample surface does not change during the period from the emissivity measurement to the following oxide-layer thickness determination. In addition, in various processes of industrial manufacture, the heating time of samples is easy to control, whereas the thickness of oxide layer is very difficult to measure. In other words, it should be more practical to determine the variation of emissivity with heating time. According to these reasons, we employ "heating time" to represent "the thickness of oxide layer" for studying the variation in emissivity with surface oxidization in this work.

This paper is organized as follows. The principle of experimental setup is described and the models of spectral emissivity are presented in the next section. The structure of experimental setup and the reproducibility of experimental results are outlined in Section 3. In Section 4, some spectral emissivity of steel 430 is reported at the wavelength of 1.5 μm over the temperature range from 800 to 1100 K. The strong oscillations of spectral emissivity are evaluated. The variation of spectral emissivity with temperature and/or heating time is discussed and modeled. Concluding remarks are given in Section 5.