Thermal Conductivity Evaluation of Thermally Grown FeO Scale on Steel

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Thermal conductivity of iron oxide scale formed on the surface of steel slabs during the hot-rolling process is a decisive factor to improve the quality of steels. There are some reports about thermal conductivity determinations of iron oxides, most of which have used sintered FeO, Fe_3O_4 and Fe_2O_3 as samples [1]. However, the actual oxide scale consists of these oxide layers and contains voids as well. It is also very difficult to estimate apparent the thermal conductivity of actual oxide scale from the thermal conductivity and volume fraction of each oxide phase. Against this background, it is practically useful to measure the apparent thermal conductivity of entire oxide scale on steel as a function of temperature. Consequently, as a first step, the present work aims to measure the thermal conductivity of thermally grown FeO scale on steel using the laser flash method.

Iron plates (99.99% purity) were used as substrates, which were oxidized at 973 K in air for 1.5-5.5 h and then heated at 1273 K in nitrogen atmosphere for 1.5-3 h to produce FeO scales about 20 and 100 µm thick on both surfaces. As shown in Figure 1, the thermal diffusivity of FeO scale was measured by the laser flash instrument with the curve fitting method [2] and multi-layered model [3], the front surface of the sample was heated by a laser pulse, and the resulting temperature change at the back surface was recorded by a radiation thermometer. In addition, the thermal diffusivity (α) was converted to the thermal conductivity (k) using the density (ρ) and heat capacity (c_p) of FeO by the equation of $k = \alpha\rho c_p$.

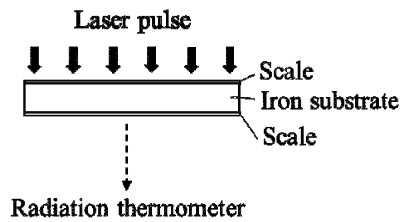

Figure 1. Schematic diagram of laser flash measurement.

Before the measurement, the samples were spray-coated with carbon powders to improve the temperature response, and the measurement was carried out in a vacuum lower than 1.2 Pa to avoid further oxidation of samples from room temperature to 1173 K.

The obtained thermal conductivity values of FeO scale increase with the scale thickness increase from 20 µm to 100 µm at room temperature, which suggests that interfacial thermal resistance occurs between the FeO scale and the iron substrate. The interfacial thermal resistance was obtained by comparing the thermal conductivity values for the FeO scale with different scale thicknesses. In addition, the thermal conductivity values obtained at 676 K depend on the heating cycle and the cooling cycle. The scanning electron microscopy observations revealed that the FeO scale layer contained Fe_3O_4 and Fe particles after the laser flash measurements, which suggests that FeO decomposed to Fe_3O_4 and Fe during the heating and affects the thermal conductivity values of FeO scale. Finally, the thermal conductivity was corrected with the obtained interfacial thermal resistance and the volume fractions of the dispersed Fe_3O_4 and Fe particales as shown in Figure 2 [4], which value at room temperature has been derived as 2.28 $Wm^{-1}K^{-1}$. The temperature coefficients of the thermal conductivity for FeO scale are mostly negative, which is dominated by the phonon mean free path.

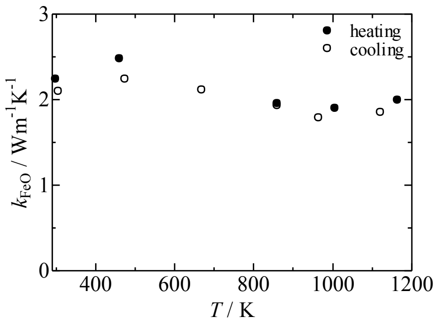

Figure 2. Thermal conductivity of FeO scale after correction.

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