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Measurement of Thermal Properties of Iron Oxide Pellets[1]

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The thermal properties of iron oxide pellets of different porosity and prepared by reduction at different rates were investigated in the range of room temperature to about 800°C. The thermal diffusivity a was measured by a laser flash method and the specific heat C_p was measured by adiabatic scanning calorimetry. The thermal conductivity was calculated from the relation $\lambda = aC_p\rho$, where ρ is the density of the specimen.

For nonreduced iron oxide pellets, the thermal diffusivity and thermal conductivity decreased with increase in temperature and porosity. The specific heat increased with increasing temperature and there was a transformation point at which the specific heat reached a maximum. In prereduced iron oxide pellets, the thermal diffusivity and thermal conductivity were very small compared with the nonreduced pellets and they gradually increased with increasing temperature. The specific heat had a minimum and a maximum at about 300 and 600°C, respectively, and the scale of these features became smaller with increase in the reduction rate.

KEY WORDS: iron oxide pellet; reduction rate; specific heat; thermal conductivity; thermal diffusivity.

1. INTRODUCTION

Generally, the iron oxide pellets employed in the raw materials of blast furnaces are made by sintering iron oxide powder. A pellet is gradually

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reduced in the furnace by the heat from the high-temperature CO gas from the combustion of cokes. The thermal properties of the pellet influence the reaction velocity in the reduction process in the furnace. Unfortunately data on these very important properties have been little reported.

In this study, the thermal diffusivity and specific heat of several specimens of iron oxide pellets of different porosity and prepared at different rates of reduction were measured in the range from room temperature to about 800°C. The thermal conductivity was calculated from the measured values of the thermal diffusivity, specific heat, and density. These thermal properties are discussed with respect to changes in porosity, reduction rate, and temperature.

2. EXPERIMENTAL EQUIPMENT AND METHOD

The thermal diffusivity was measured by a laser flash method. In this method, the thermal diffusivity is determined from a temperature versus time curve. The temperature at the back surface of a specimen is measured while the front surface is being uniformly heated by a laser flash. A diagram of the experimental setup is shown in Fig. 1. The temperature change of the specimen was measured by a chromel–alumel thermocouple of 0.08 mm diameter welded by an electrically conducting silver paste (Arzerite) to the center of the back surface. A detailed description of the equipment has been given previously [1].

The specific heat was measured using an adiabatic scanning calorimeter (type SH-3000 manufactured by Shinku-Riko Co.), as shown in Fig. 2.

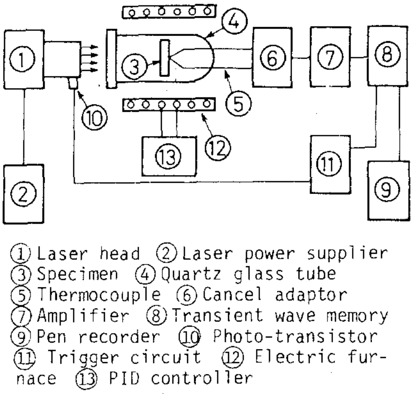
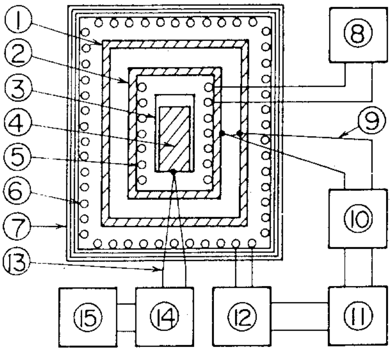


Fig. 1. Diagram of measuring apparatus for the thermal diffusivity.



① Uniform temperature vessel ② Adiabatic vessel ③ Specimen vessel ④ Specimen ⑤ Internal heater ⑥ External heater ⑦ Reflective plate ⑧ Constant wattage supplier ⑨ C-A thermocouple ⑩ Amplifier ⑪ PID controller ⑫ SCR out put ⑬ P-R thermocouple ⑭ Digital voltmeter ⑮ Personal computer

Fig. 2. Diagram of measuring apparatus for the specific heat.

The thermal insulation of the adiabatic vessel was performed as follows. The specimen and adiabatic vessel were heated continuously by supplying a constant electric power to the internal heater while the electric current to the external heater was controlled simultaneously by a PID unit, so that the temperature of the uniform-temperature vessel was always equal to that of the adiabatic vessel. Thus the specific heat of the specimen was determined from the relation between the electric power and the temperature rise of the specimen per unit time.

In measurements with pure nickel as a standard, the deviation from the values in the literature [2, 3] was within 7% for the thermal diffusivity and within 4% for the specific heat for temperatures 50–800°C.

3. EXPERIMENTAL SPECIMENS

The characteristics of the nonreduced and prereduced iron oxide pellets employed in this experiment are shown in Tables I and II, respectively. Specimens A1–A6 and B1–B4 were employed in measuring the thermal diffusivity, whereas specimens C1–C4 were employed in measuring the specific heat. The shape of the specimen was a disk of 11 mm diameter and 3 mm thickness for the thermal diffusivity measurements and a

Table I. Characteristics of Nonreduced Iron Oxide Pellets

Specimen	Density ($g \cdot cm^{-3}$)	Porosity (%)
A1	2.68	48.2
A2	2.71	47.6
A3	2.98	42.4
A4	3.02	41.6
A5	3.25	37.3
A6	3.26	37.0
C1	2.02	60.9
True density 5.17 $g \cdot cm^{-3}$		

cylinder of 15 mm diameter and 18 mm length for the specific heat measurements. The apparent density listed in the tables was determined from the buoyancy of the specimen in mercury, whereas the true density was determined by using a pycnometer. The porosity was calculated from the difference between the apparent density and the true density.

The specimens were prepared according to the following procedure. Pure Fe_2O_3 powder was mixed with 15 wt % water and then pressed by a cylindrical die under presure (4–20 MPa). After natural drying, the specimen was dried again with a dryer for 2 h at 110–120°C, then was sintered for 30 min. at 1100°C in the atmosphere. The reduction procedure was as follows. A sintered iron oxide pellet was placed in a reactor tube made of quartz glass and was reduced by the steady flow of CO gas at 800°C for a given time and was then cooled immediately by N_2 gas. The reduction rate in Table II was determined from the mass difference before and after reduction.

Table II. Characteristics of Prereduced Iron Oxide Pellets

Specimen	Reduction rate(%)	Density ($g \cdot cm^{-3}$)
B1	16.0	2.74
B2	26.2	2.32
B3	41.6	2.16
B4	70.1	1.39
C2	43.3	2.43
C3	70.9	2.14
C4	91.5	1.90

4. RESULT AND CONSIDERATION

Figures 3 and 4 show the relation between the thermal diffusivity a and the temperature t for the nonreduced iron oxide pellets. In these figures, the thermal diffusivity of each specimen is about $(2\text{–}4) \times 10^{-6}$ $m^2 \cdot s^{-1}$ at room temperature. It decreases rapidly with increasing temperature up to around 680°C, at which it begins to increase with increasing temperature. The temperature 680°C at which the thermal diffusivity becomes minimum is considered to be the transformation point of iron oxide. Figure 5 shows the temperature dependence of the specific heat C_p for specimen C1. Since the specific heat is not influenced by the porosity, the specific heat of C1 is taken to represent that of specimens A1–A6. The specific heat of C1 is about 0.55 $kJ \cdot kg^{-1} \cdot K^{-1}$ at room temperature and increases with increasing temperature. It has a maximum value at about 680°C and decreases rapidly for temperatures above 680°C. The temperature at which the specific heat becomes maximum agrees with the above-mentioned transformation point of iron oxide. The experimental results in Fig. 5 agree well with the literature values [4].

The thermal conductivity λ was calculated from the relation $\lambda = aC_p\rho$, where ρ is the density of the specimen. In the calculation, it was assumed

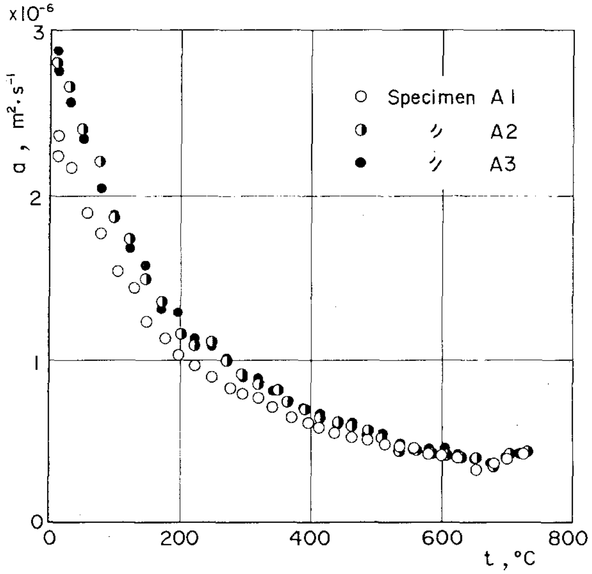


Fig. 3. Thermal diffusivity of nonreduced iron oxide pellets; specimens A1–A3.

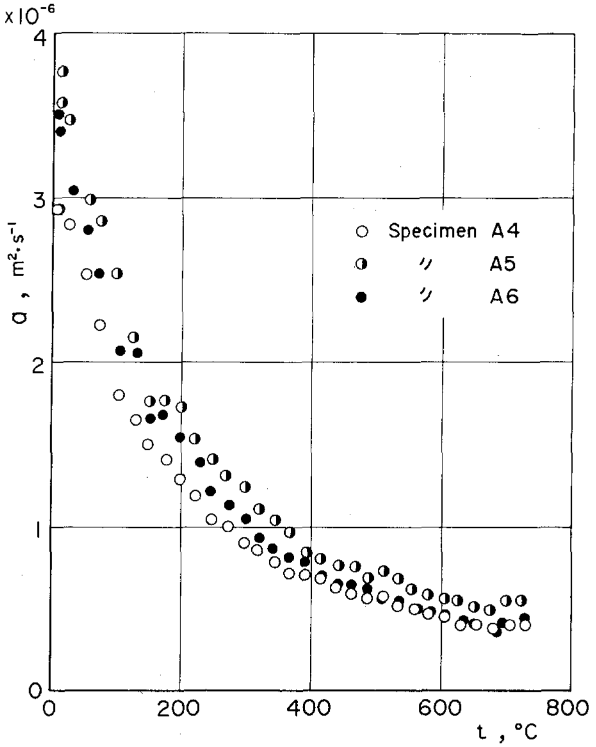


Fig. 4. Thermal diffusivity of nonreduced iron oxide pellets; specimens A4–A6.

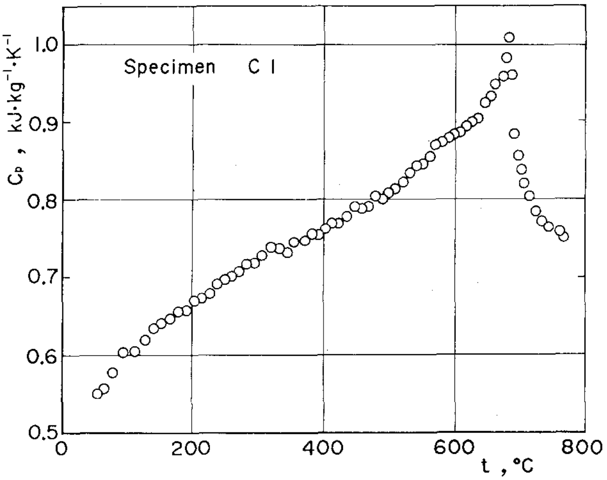


Fig. 5. Specific heat of nonreduced iron oxide pellets.

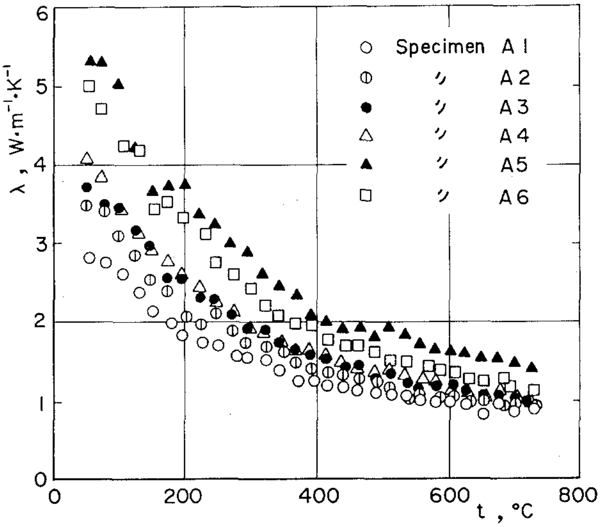


Fig. 6. Thermal conductivity of nonreduced iron oxide pellets.

that the density was constant for all temperatures. Figure 6 shows the temperature dependence of the thermal conductivity λ for the nonreduced iron oxide pellets. The thermal conductivity decreases considerably with increasing temperature for low temperatures, but changes slightly for temperatures above 600°C. In this figure, the peak of the transformation point at about 680°C does not appear. Not enough data on the thermal conductivity and the thermal diffusivity for iron oxide pellets have been reported to provide a comparison with the present results. Since the pellet is sintered, it is thought that its thermal conductivity is larger than that of iron oxide powder but is smaller than that of the metal iron.

Now we consider the case of prereduced iron oxide pellets. Figure 7 shows the relation between the thermal diffusivity and temperature. The thermal diffusivity is from about one-fifth to one-tenth of that of the nonreduced iron oxide pellets. In the specimen with the reduction rate $R = 16\%$ the thermal diffusivity decreases rapidly with increasing temperature in a similar manner to the case of the nonreduced iron oxide pellets for temperatures about 600°C. In other specimens the thermal diffusivity increases initially and seems to have a peak between 400 and 500°C. On the other hand, the relation between the thermal diffusivity and the reduction rate shows the thermal diffusivity to decrease with increase in reduction rate for $R = 41.6\%$ and below, but increase for $R = 70.1\%$. Generally the composition of the prereduced iron oxide pellets is inhomogeneous because the reduction process does not proceed uniformly in the

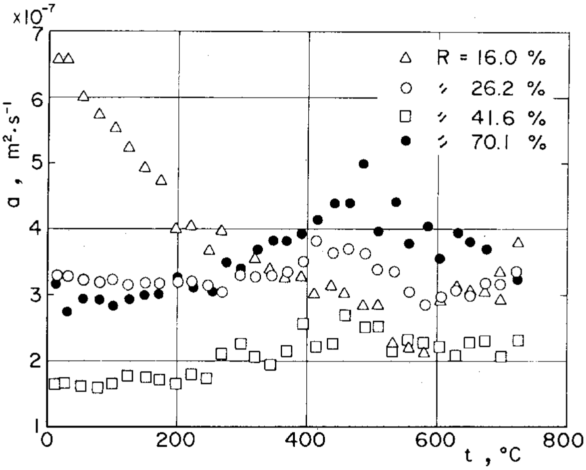


Fig. 7. Thermal diffusivity of prereduced iron oxide pellets.

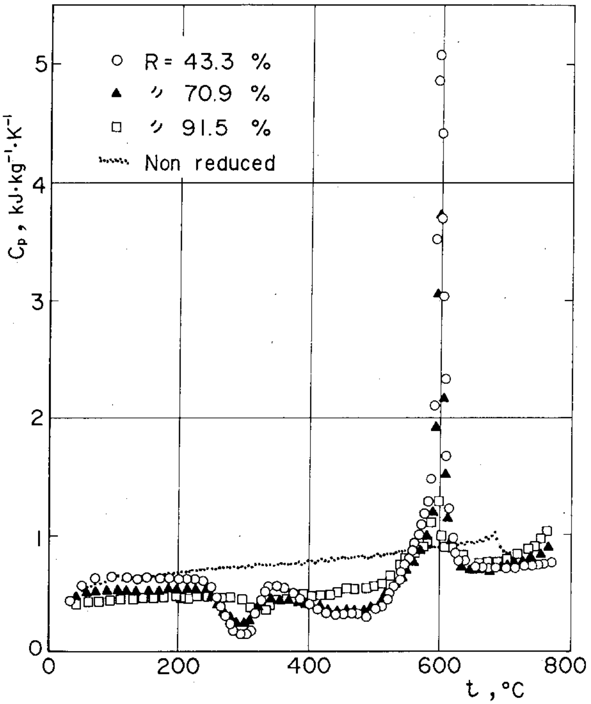


Fig. 8. Specific heat of prereduced iron oxide pellets.

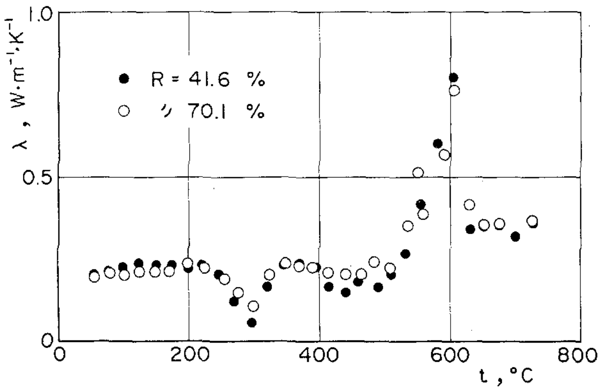


Fig. 9. Thermal conductivity of prereduced iron oxide pellets.

whole specimen but gradually starts from the surface of the specimen. Therefore it would seem that the experimental *a* values in Fig. 7 do not clearly indicate the relationship with the reduction rate.

Figure 8 shows the relation between the specific heat and the temperature for the prereduced iron oxide pellets. In this figure, the specific heat of a nonreduced iron oxide pellet is shown for comparison. The same trend was observed in the specific heats for the specimens with $R = 43.3\%$ and 70.9%, and they showed a minimum value at about 300°C and a very significant maximum value at about 600°C. However, in the specific heat for the $R = 91.5\%$ specimen the features at 300 and 600°C become rather small and the peak at 600°C is about one-fourth of that of the $R = 43.3\%$ specimen. Comparing the specific heat of the prereduced and nonreduced iron oxide pellets, we see that the specific heat of the nonreduced pellet is generally larger than that of the prereduced pellets except for the peak at 600°C and does not have the features at 300 and 600°C. Figure 9 shows the calculated values of the thermal conductivity for the prereduced iron oxide pellets. The thermal conductivity is less than one-tenth of that of the nonreduced pellets at room temperature and is less than half for high temperatures. Though the thermal conductivity of the nonreduced specimens decreases with increasing temperature, that of the prereduced specimen increases as a whole. The change of λ at 300 and 600°C is caused by the features in the specific heat in Fig. 8, since λ is obtained by calculation.

5. CONCLUSION

The following results were obtained by measuring the thermal properties of nonreduced and prereduced iron oxide pellets.

The thermal diffusivity and thermal conductivity of nonreduced pellets decrease with increase in temperature and porosity. The specific heat of the nonreduced pellets increases initially with increasing temperature and has a transformation point at about 680°C, where the specific heat becomes maximum. For the prereduced pellets, the thermal diffusivity and thermal conductivity are considerably smaller than those of the nonreduced pellets at room temperature and increase approximately with increasing temperature except in the case of the specimen with $R = 16\%$. The specific heat of the prereduced pellets has a minimum and a maximum at about 300 and 600°C, respectively, but increases as a whole with increasing temperature.

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