Electric Resistivity of Molten Fe-Ni and Fe-Co Alloys*

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A knowledge of the structure of molten iron alloys must be established before a complete understanding of the equilibrium and the kinetics of reactions in iron- and steelmaking processes can be attained. The structure of molten iron alloys has hitherto been speculated indirectly from the experimental data on their physical properties such as viscosity, diffusivity, density, *etc.*, because application of X-ray or neutron diffraction technique is difficult experimentally at steelmaking temperature.

Electric resistivity is one of the structure-sensitive properties but it has scarcely been investigated for molten iron alloys not only theoretically but also experimentally. In the present work, the electric resistivities of molten alloys of Fe-Ni and Fe-Co have been measured as a portion of systematic investigations on the structure of molten iron alloys.

Experimental

The electrodeless, rotating field method has been applied in the present work to the measurement of the electric resistivity of molten iron alloys.

When a metal specimen is placed in the center of a rotating magnetic field, an eddy current will be induced in the specimen and the specimen will be subjected to a rotational moment arising from the mutual interaction between the eddy current and the magnetic field. In case of a cylindrical specimen of radius R and length L , the rotational moment M is given by¹⁾

$$M = \frac{\pi}{4} \cdot \frac{1}{\rho} \cdot \omega L R^4 H^2 \dots\dots\dots (1)$$

where ρ denotes the electric resistivity of the metal sample and H and ω denote the strength and the angular velocity respectively of the rotating magnetic field.

When a crucible containing the metal specimen is suspended by a wire and the rotational moment induced in the specimen is balanced by the torsion of the wire, the moment M will be proportional to the torsional angle of the wire. The strength of the rotating magnetic field H will be proportional to the current flow I , which is supplied to the coils of the electro-magnet to create the magnetic field. Equation (1) will, therefore, be modified as

$$\rho = \frac{1}{Q} \cdot (V - K_v) \left(\frac{I^2}{\alpha_e} \right) \dots\dots\dots (2)$$

where V denotes the volume of the specimen, K_v the

correction for the end effects of the specimen, α_e the torsional angle of the suspension wire corrected for several factors (as to the details for the corrections, refer

- (a) Tungsten suspension wire
- (b) Mirror
- (c) Window
- (d) Brass disk
- (e) Brass rod
- (f) Graphite rod
- (g) Silica jacket
- (h) Electro-magnet
- (i) Graphite heating element
- (j) Alumina crucible with metal specimen
- (k) Thermocouple (Pt-30%Rh-Pt-6%Rh)
- (l) Vacuum line
- (m) Power supply

Fig. 1. Schematic cross section of the apparatus for measuring electric resistivity of molten metals

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to Roll *et al.*^{2,3)}, and Q a constant characteristic to the apparatus used. The apparatus constant Q can be determined by measuring the torsional angle using mercury as a standard specimen, the resistivity of which is accurately known. The electric resistivity of a molten metal in question is thus determined from Eq. (2) by measuring the torsional angle α of the suspension wire at a constant current I in the coils of the electromagnet.

The experimental apparatus is schematically shown in Fig. 1. A metal specimen of about 10 g contained in a recrystallized alumina crucible, 10 mm in I.D. and 62 mm in height, was suspended by a tungsten wire of 0.12 mm in diameter. The specimen was heated under reduced pressure of 0.05 to 0.1 mmHg by a graphite heating element. The heating element was made from two co-axial graphite cylinders through which the current flowed counter-currently, in order that the magnetic field introduced by the current flowing through the element could be cancelled out. The torsional angle was measured by the device of a mirror attached to the suspension system and a telescope with a lamp-scale. Alloy specimens were prepared by melting together the pure component metals, the purity of each being 99.9% or higher, in a vacuum induction furnace. The density data reported by Saito *et al.*⁴⁾ were used to calculate the volume of the specimen, V in Eq. (2), at the experimental temperature. In the present work, the probable error accompanied with the measured resistivity values was $\pm 0.5\%$.

Results and Discussions

The observed values of resistivity of molten Fe-Ni and Fe-Co alloys are found to increase linearly with increasing temperature in the temperature range of measurement up to 1625°C. The results are summarized in Table 1, in which the coefficients obtained by a least square fit of the data points to a straight line are shown.

Figure 2 shows the reduced resistivity at 1600°C for Fe-Ni and Fe-Co alloys as a function of concentra-

tion. The reduced resistivity is defined as the deviation of the observed resistivity from a linear combination of the pure component resistivities. The reduced resistivity-composition curve for molten Fe-Ni alloy system is nearly parabolic with a maximum at about 60%Ni and takes an abnormally small values at about 75%Ni. The reduced resistivity of molten Fe-Co alloys is negative in contrast with that of Fe-Ni alloys and the reduced resistivity-composition curve shows a minimum at about 50%Co.

The abnormal behaviors as described above have also been found for other properties of these alloys. For examples, the solubility of carbon in molten Fe-Ni alloys⁵⁾ exhibits a minimum at about 75%Ni and the viscosity of the alloy⁶⁾ takes a maximum at the same composition. These facts are considered to be indicative of the possibility of formation of a cluster like FeNi₃ in Fe-Ni melts.⁶⁾ In molten Fe-Co alloys, the solubility of hydrogen⁷⁾ shows a sharp minimum at about 50%Co and the magnetic susceptibility⁸⁾ exhibits an abrupt increase at the same composition. These facts are explained⁸⁾ by the possibilities either of a transition of the structure of molten Fe-Co alloys from a structure resembled to that of δ -iron to another structure characteristic for pure liquid cobalt or of the formation of a cluster like FeCo.

The present results on the electric resistivity of molten alloys of Fe-Ni and Fe-Co mentioned above may be considered to be another evidences for the structural peculiarities of these melts as assumed by previous investigators.^{6,8)} But theoretical interpretation of the present results is not possible at present, because the electronic structure of the transition metals in the molten state is not yet known.

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Table 1. Electric resistivities of molten Fe-Ni and Fe-Co alloys*

		α ($\mu\Omega\cdot\text{cm}/^\circ\text{C}$)	β ($\mu\Omega\cdot\text{cm}$)
Fe-Ni alloys (at%Ni)	0 (Fe)	0.0434	71.16
	20.0	0.0403	78.33
	39.6	0.0352	88.01
	59.8	0.0232	102.28
	74.4	0.0259	83.67
	79.5	0.0396	61.46
	100 (Ni)	0.0280	44.32
Fe-Co alloys (at%Co)	20.7	0.0475	62.31
	39.8	0.0495	56.08
	49.4	0.0429	63.79
	59.3	0.0475	56.00
	79.8	0.0478	54.40
	100 (Co)	0.0384	69.07

* The constants fit the equation ρ ($\mu\Omega\cdot\text{cm}$) = αT ($^\circ\text{C}$) + β .

Fig. 2. Reduced electric resistivity (measured resistivity minus a linear combination of the pure component resistivities) at 1600°C

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