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Research of electrical conductivity of synthetic powders

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ABSTRACT

Purpose: This paper describes the electrical conductivity of liquid phase powders and laboratory research of electrical conductivity of synthetic powders.

Design/methodology/approach: Research of electrical conductivity of liquid synthetic slag was performed using voltmeter-ammeter method on the specially designed research stand.

Findings: The electrical conductivity of slag depends on the chemical composition of the liquid slag, which is related to their ionic structure. The electrical conductivity is determined by the dimensions of the ions, their number and mobility as a function of the viscosity of the liquid in which they are.

Research limitations/implications: Laboratory studies of electrical conductivity of liquid powders should be the basis for further studies crystallizer powders used in continuous casting conditions.

Practical implications: The chemical composition of powders (ion) can cause changes in the lubrication conditions in the near-meniscus zone in continuous casting mold and can influence on the surface quality on the continuous casting ingots.

Originality/value: This paper presents the result of research of electrical conductivity CaO-SiO_2-Al_2O_3-FeO-MgO-K_2O powders.

Keywords: Multifunctional materials; Electrical properties; Casting; Molten slag; Electrical conductivity

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PROPERTIES

1. Introduction

Electrical conductivity is physical quantity characterizing electrical conductivity of materials – ability to transfer electrical charges by positive or negative carriers (cations, anions) under the influence of an external electric field.

It's the opposite of resistance, which is a measure of the susceptibility of an item to the flow of electrical current. The phenomenon of conduction of electrical current through the liquid slag is the evidence of the ionic theory of the liquid slag construction. In the case when the ions are different sizes, according to Frenkel's theory, the conductivity depends on the most mobile ions (cations).

The mobility of cations – and consequently the electrical conductivity of liquid slag – depends on the degree of "interoperability" with the surrounding anions and temperature.

Electrical conductivity depends on the chemical composition of the liquid slag, which is related to their ionic structure. Different values of conductivity occur in the slag system when the ions are free, others when the ions build complex compounds [1].

The electrical conductivity is determined by the dimensions of the ions, their number and mobility as a function of the viscosity of the liquid in which they are.

The highest electrical conductivity have a slag rich in FeO and MnO – except of ion conductivity they also have electron conductivity. Electron conductivity of the slag can be explained by the presence in them of the metal cations in both valency 2 and 3 ($Fe^{3+} + e \rightarrow Fe^{2+}$).

The electrical conductivity of liquid slag is a characteristic depending not only on the nature of the slags themselves but also upon many factors affecting the ion mobility – as structural components of the liquid slag. The value of electrical conductivity decreases rapidly (about 100 times) when slag solidifies [6].

2. Methodology of research of electrical conductivity of synthetic slags

For laboratory research five synthetic powders with different basicity – Fig. 1 were prepared. Powders were prepared in the laboratory conditions from chemically pure components (Table 1).

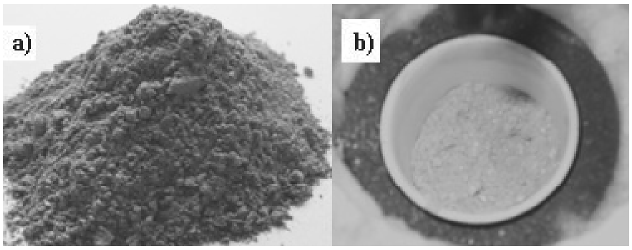

Fig. 1. View of powder 1 (a), view of powder 2 in furnace (b)

Table 1.
The chemical composition of synthetic powders

	Chemical compositions, % mass.						Basicity
	CaO	SiO_2	Al_2O_3	FeO	MgO	K_2O	$\frac{\%CaO}{\%SiO_2}$
1	29.27	46.21	13.86	4.19	-	6.47	0.633
2	31.87	35.86	9.56	6.46	4.78	11.47	0.888
3	41.14	37.97	9.49	-	4.75	6.65	1.083
3A	41.34	38.15	4.77	4.29	4.77	6.68	1.084
4	41.30	29.54	9.53	3.43	4.76	11.44	1.398

Their preparation consisted of adequate mixing and annealing to remove moisture contained in them. Research of electrical conductivity of liquid synthetic slag was performed using voltmeter-ammeter method on the specially designed research stand (schematic diagram was showed in Fig. 2 and view of research stand was shown in Fig. 3).

The main structural elements of the research stand were:

- crucible of aluminum oxide placed in graphite crucible;
- electrical part, consisting of:
  - AC adapter,
  - digital multimeter UT60A, UT60D, UT70B.

Multimeters are modern digital meters enabling measurement of voltage and alternating current, resistance, capacitance, temperature, frequency, and verify circuit continuity. Connection the computer with the multimeters by the RS232C serial port enabled automatic recording of data (Fig. 4).

- a computer system for recording the results of measurements;

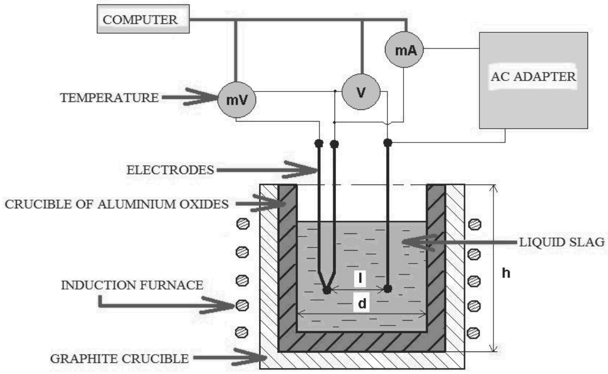

Fig. 2. Schematic diagram of the research stand for measuring electrical conductivity of liquid slag

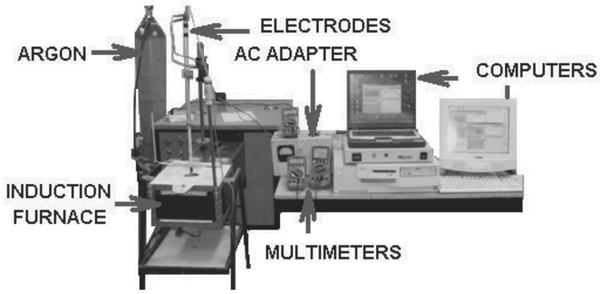

Fig. 3. View of research stand for measuring electrical conductivity of liquid slag

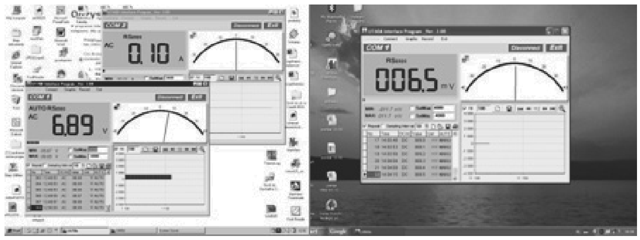

Fig. 4. View of the computer screen with measured data

- platinum electrodes: PtRh18 and Pt. Electrodes were placed in a specially constructed measuring probe (Fig. 5);

Probe was a thermocouple arrangement with platinum electrodes. These electrodes were encapsulated in a quartz tube. The whole fastened to the metal case equipped with a terminal strip

- induction furnace for melting steel PI 20 ELKON TYPE.

Before realization the appropriate measurements the constant of crucible was determined. For its designation as a model of electrical conductivity 0.1 molar aqueous solution of KCl was used.

In the second phase of the research electrical conductivity measurements of prepared powders were conducted. After they melted in an induction furnace and obtained a homogeneous liquid phase measuring electrodes (probe) were introduced to them in each case to the same depth (Fig. 6). Measurements were carried out in cooling the molten slag.

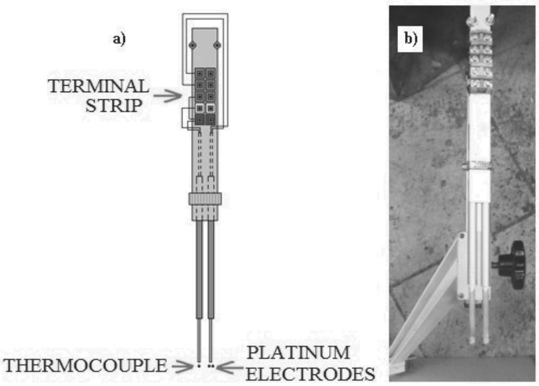

Fig. 5. Probe measurement: a) schematic diagram, b) view of probe

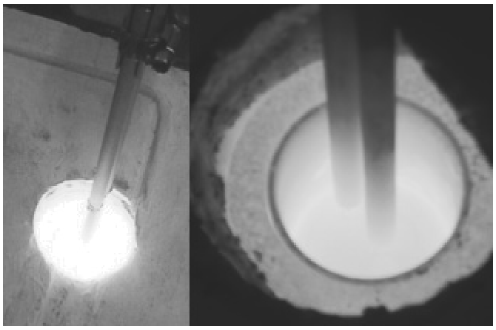

Fig. 6. Introduction of electrodes into the liquid slag

Measurement data: current and voltage flowing current and the electromotive force in mV thermocouple were automatically stored in computer memory. Knowing the voltage and current flowing through the liquid phase of the slag its electrical resistance R_Z was designated [10]. And then based on formula (1) electrical conductivity of liquid slag was determined:

$$\chi_z = \frac{K}{R_Z} \tag{1}$$

where: K – designated the "constant of crucible", m^{-1},
R_Z – electrical resistance of liquid phase powders between the electrodes, Ω.

Electromotive force (expressed in mV) was used to determine the temperatures of the liquid powders – based on the characteristics of PtRh18-Pt thermocouple according to the PN-59/M-53854 norm. The research of specific electric conductivity was carried out for the liquid synthetic slag powders 1, 2, 3, 3A and 4 (table 1) – according to the presented methodology.

3. Results of the research of synthetic powders electrical conductivity

Figures 7-11 show the results of the research of synthetic powders electrical conductivity. With increasing temperature, in the range from 960°C (1233 K) to 1325°C (1598 K), electrical conductivity of liquid synthetic slag 1, 2, 3, 3A and 4 increases.

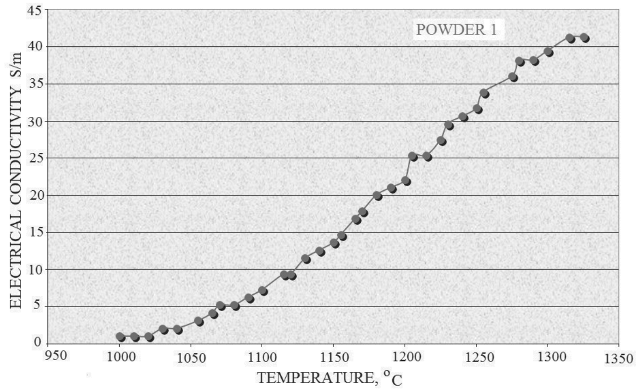

Fig. 7. Dependence of electrical conductivity of liquid synthetic powder 1 on temperature

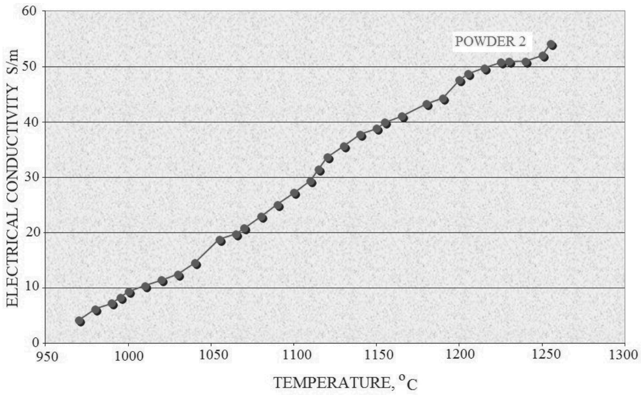

Fig. 8. Dependence of electrical conductivity of liquid synthetic powder 2 on temperature

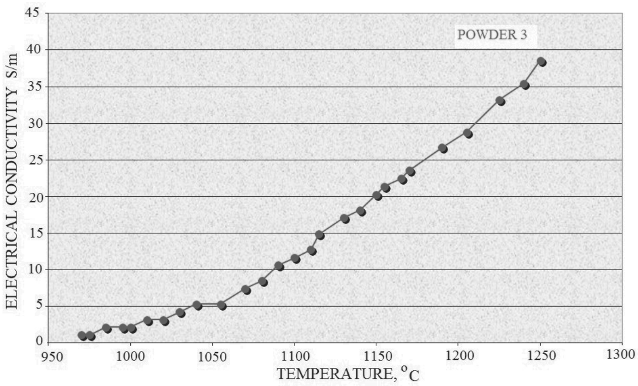

Fig. 9. Dependence of electrical conductivity of liquid synthetic powder 3 on temperature

Powder 4 is characterized by the highest electrical conductivity in the range temperature from 1275°C (1548 K) to 1325°C (1598 K). The powder 4 reached electrical conductivity value of 81.96 S/m in 1325°C (1598 K).

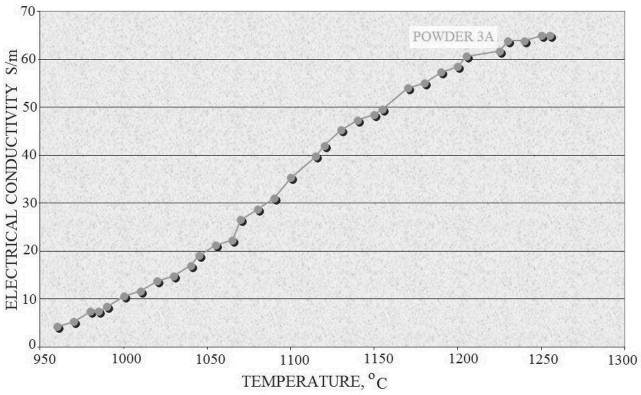

Fig. 10. Dependence of electrical conductivity of liquid synthetic powder 3 A on temperature

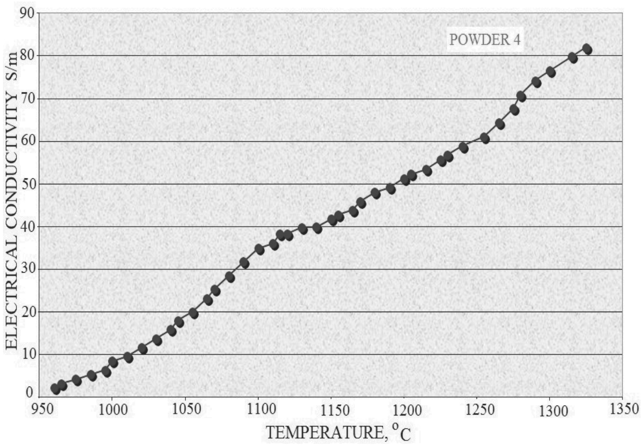

Fig. 11. Dependence of electrical conductivity of liquid synthetic powder 4 on temperature

The electrical conductivity for powder 1 has value of 41.35 S/m in this temperature. In temperature 1255°C (1528 K), in which all powders were in the liquid state, the powder 3A had the highest electrical conductivity. The electrical conductivity value was 64.99 S/m.

The liquid phase of powder 4 has reached a similar value (61 S/m). The lower value of electrical conductivity (54.13 S/m) was obtained for powder 2 in 1255°C (1528 K) temperature.

Slag powders 1 and 3 in the whole range of temperature were very different from the values of specific electrical conductivity of slag powders 2, 3A and 4. These differences can be assessed at 45%. The powder number 1 had the lowest value of electrical conductivity in the whole range of temperature (up to 1250°C). The electrical conductivity ranged from 6.29 to 31.75 S/m.

Research of electrical conductivity was conducted in the cooling mode liquid powder from 1325°C (1598 K) temperature for powders 1 and 4. For powders 2 and 3A electrical conductivity was determined in the cooling mode from 1255°C (1528 K). In the case of 3 powder this temperature was 1250 °C (1523 K) [11].

The observed differences in electrical conductivity for various liquid powders may stem from diverse chemical composition: cations content, FeO content and ions oxygen content (in the case of 4 powder). In temperature 1000°C (1273 K),where the powders were already semi-liquid and solid, the electrical conductivity values were in the range from 1.04 to 10.5 S/m.

4. Conclusions

Basing on the research mentioned above along with the description of results, it was concluded that:

1) the highest electrical conductivity in range temperature (from 1275°C (1548 K) to 1325°C (1598 K)) characterized powder 4. The powder 4 reached electrical conductivity value 81.96 S/m in 1325°C (1598 K),
2) the powder number 1 had the lowest value of electrical conductivity in the whole range of temperature (up to 1250°C). The electrical conductivity ranged from 6.29 to 31.75 S/m,
3) with increasing temperature electrical conductivity of liquid synthetic slag increases.

A comparison of the results of liquid slag electrical conductivity indicates that their electrical conductivity is a function of temperature and chemical composition – ionic composition. The liquid phases of synthetic powders are ionic conductors of electricity.

References

[1] S. Jadźwiński, Thermodynamics and kinetics of metallurgical processes, Śląsk, 1966 (in Polish).

[2] O.A. Jesin, P.W. Gield, Fiziczieskaja chimia piromietałłurgiczieskich praciessow, cz. II. Mietałłurgia, 1966.

[3] Q. Jiao, N.J. Themelis, Correlations of electrical conductivity to slag composition and temperature, Metallurgical and Materials Transactions B 19 (1988) 133-140.

[4] S. Holewiński, Blast furnace slag, Śląsk, Katowice, 1965 (in Polish).

[5] J.A. Onajew, Fizyko-chemiczieskije swojstwa szlaków w cwietnoj mietałurgii. Nauka, Ałma-Ata, 1972.

[6] B. Sikora, M. Zieliński, The density, surface tension, viscosity and electrical conductivity of molten systems of CaO-Al_2O_3-CaF_2 slag, Metallurgist 9 (1974) 433-437 (in Polish).

[7] S. Hara, H. Hashimoto, K. Ogino, Electrical Conductivity of molten slag for electro-slag remelting, Transactions ISIJ 23 (1983) 1053-1058.

[8] A. Kondratiev, J. Evgueni, A quasi-chemical viscosity model for fully liquid slags in the Al_2O_3-CaO-'FeO'-SiO_2 System, Metallurgical and Materials Transactions B 36 (2005) 623-638.

[9] W. Chiho, X. Shunhua, Electrical conductivity of molten slags of CaF_2+Al_2O_3 and CaF_2+ Al_2O_3+CaO systems for ESR, ISIJ International 33/2 (1993) 239-244.

[10] A. Staronka, A. Cyuńczyk, Methods of measurement of electrical conductivity and transfer numbers in metallurgical slags, Metallurgist 7-8 (1966) 338-343 (in Polish).

[11] Z. Kudliński, B. Sikora, A. Sorek, Research of electrical properties of liquid phases of casting powders, Proceedings of the International Scientific Conference "Teorie a Praxe Vyroby a Zpracowani Oceli", Roznov pod Radhostem, Czech Republic, 2008, 90-96.