ZHANG, J. The recent trends in research on slags in China. *VII International Conference on Molten Slags Fluxes and Salts,* The South African Institute of Mining and Metallurgy, 2004.

The recent trends in research on slags in China

J. ZHANG
Metallurgical Engineering School, University of Science and Technology Beijing, Beijing, China

The author recently has reviewed the publications on the slag-related research in China since the Sixth International Conference on Molten Slags, Fluxes and Salts in June, 2000. In fundamental aspects, the physical property predictions and measurements, slag-metal reactions, slag-refractory reactions have received close attention, and are briefly described here in this report. More than half of slag-related publications deal with plant investigations due to the requirement of technological improvements and environmental protection. In the present paper, the research on slags in various treatments related to clean steel production and the utilization of the waste slags is briefly reviewed.

Introduction

The author recently has surveyed the slag-related research in China since the Sixth International Conference on Molten Slags, Fluxes and Salts in 2000. From the publications, it has been noticed that the physical property predictions and measurements, slag-metal reactions, as well as slag-refractory reactions have received close attention. This could be due to the requirement of the operation optimization and dynamic control of the melting and refining processes. In the following sections, some representative studies will be described.

Compared with the situation in the last years of the 20th century, slag-related publications from industry have been remarkably increasing. The contents have related to various treatments for clean steel production and utilization of the waste slags. This trend could be caused by the demands to technological improvements and environmental protection. The publications in these areas will be briefly reviewed.

Physical properties of slags

Viscosity

Recently Zhong, X.M. *et al.* proposed a model to evaluate the viscosity in a molten ternary slag system from the viscosity data in the component binaries or the known viscosity in the molten region of the ternary[1]. Figure 1 is the model presentation diagram where 'O' represents an arbitrary point within the molten area of KLMNPQ in the ternary,1–2–3. The viscosity for the melt at point O can be calculated using the following linear summation:

$$\eta_O = W_A\eta_A + W_B\eta_B + W_C\eta_C \quad [1]$$

where η_A, η_B and η_C respectively denote the viscosities of the three vertexes A, B and C of ABC, while W_A, W_B, and W_C are the weighted factors and can be determined using the following equations:

$$W_A = \frac{S_{\Delta OBC}}{S_{\Delta ABC}},\ W_B = \frac{S_{\Delta OAC}}{S_{ABC}},\ W_C = \frac{S_{\Delta OAB}}{S_{\Delta ABC}} \quad [2]$$

In Equation [2], $S_{\Delta ABC}$, $S_{\Delta OBC}$, $S_{\Delta OAC}$ and $S_{\Delta OAB}$ in Equation [2] respectively represent the areas of the corresponding mass triangles illustrated in Figure 1. Each of the areas can be calculated using the mole fraction values in the relevant mass triangle. For instance, $S_{\Delta ABC}$, the area of ΔABC, can be calculated using

$$S_{\Delta ABC} = \frac{\sqrt{3}}{4}\begin{vmatrix} x_1^A x_1^B x_1^C \\ x_2^A x_2^B x_2^C \\ x_3^A x_3^B x_3^C \end{vmatrix} \quad [3]$$

where x expresses the mole fraction; the subscripts 1, 2 and 3—the components 1, 2 and 3; and superscripts A, B and C— the points A, B and C shown in Figure 1, respectively.

The viscosities in several molten slag systems were calculated. Figure 2 shows the calculated results for CaO-Al_2O_3-CaF_2 system at 1773 K using the model and the experimental data by Mills[2]. Figure 3 is another example calculated for Re_xO_y-CaF_2-SiO_2 system at 1873 K. In this Figure, the viscosities measured for the binaries by Malkov *et al.*[3] were used for the calculation. The comparison of calculated iso-viscosity lines with the experimental result for the ternary by the same authors shows a good agreement.

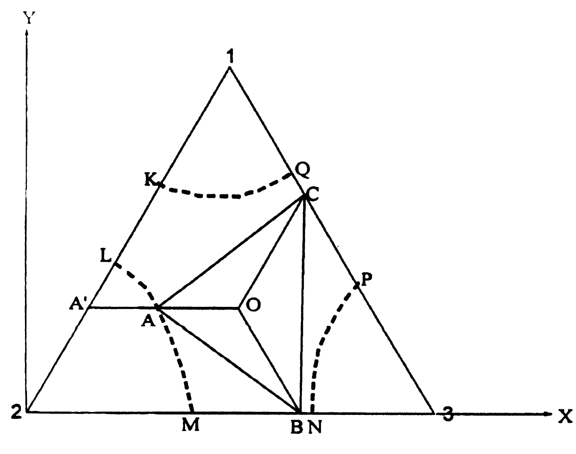

Figure 1. Schematic presentation of the 'mass triangle' model

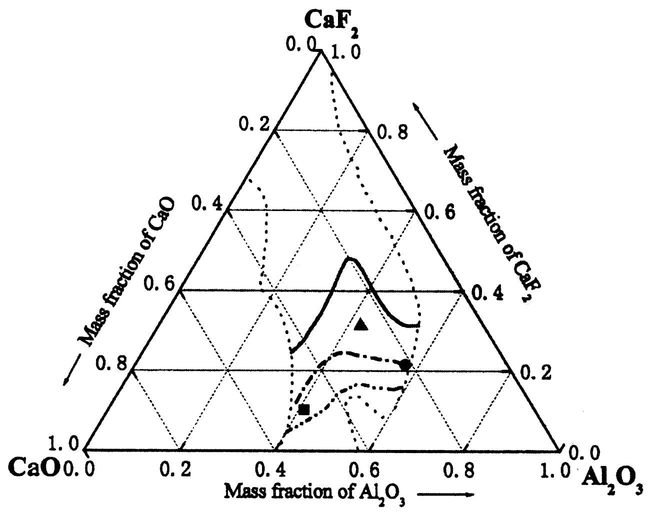

Figure 2. The calculated iso-viscosity lines in CaO-Al$_2$O$_3$-CaF$_2$ system at 1773 K—0.1 Pa·s,—·— 0.2 Pa·s,—··—0.3 Pa·s, · · · · boundary
Experimental data: ▲ 0.19 Pa·s, • 0.243 Pa·s, ■ 0. 429 Pa·s

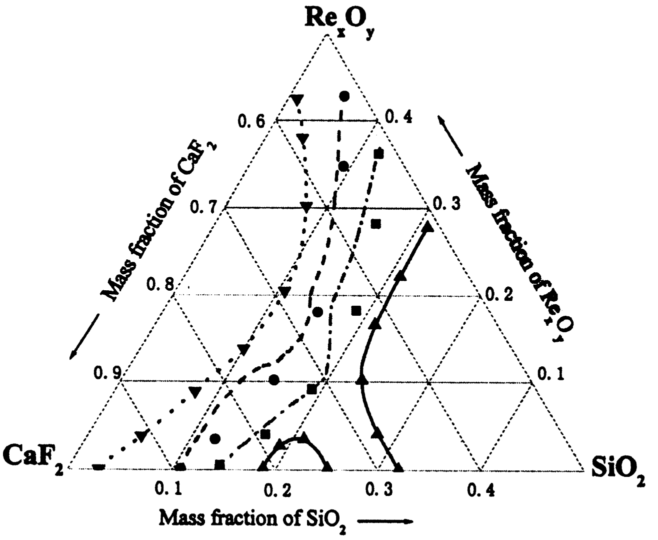

Figure 3. Calculated iso-viscosity lines in Re$_x$O$_y$-CaF$_2$-SiO$_2$ system at 1873 K· · · · 0.01Pa·s, - - - 0.02 Pa·s, - · - · - 0.03 Pa·s, -0.04 Pa·s
Experimental data: ▼ 0.01Pa·s, 0.02 • Pa·s, ■ 0.03 Pa·s, ▲ 0.04 Pa·s

Regarding the experimental aspect, Liu C.J. measured viscosity in CaO-SiO$_2$-Na$_2$O-CaF$_2$-Al$_2$O$_3$-MgO system[4]. Regression analysis was used for processing the experimental data obtained at 1300°C, generating the following correlation of the viscosity with the basicity and the flux composition:

$$\eta(Pa\cdot s) = 3.799 - 3.6765R - 0.0733\ (\%NaCO_3) - 0.1116\ (\%CaF_2) + 0.0473\ (\%Al_2O_3) - 0.0394\ (\%MgO) \ 0.0368R\ (\%NaCO_3) + 0.0541R(\%CaF_2) - 0.0046R\ (\%Al_2O_3) + 0.0264R\ (\%MgO) + 0.0012\ (\%NaCO_3)(\%CaF_2) - 0.0012\ (\%NaCO_3)(\%Al_2O_3) + 0.0004\ (\%NaCO_3)(\%MgO) - 0.0007\ (\%CaF_2)(\%Al_2O_3) + 0.0010\ (\%CaF_2)(\%MgO) - 0.0023\ (\%Al_2O_3)(\%MgO) + 0.8903R^2 + 0.0003\ (\%NaCO_3)^2 + 0.0007\ (\%CaF_2)^2 + 0.0002\ (\%Al_2O_3)^2 + 0.0001\ (\%MgO)^2 \quad [4]$$

where R = %CaO/%SiO$_2$ (The symbol % that appears in this paper only refers to mass percent). The relationship of crystallization temperature with the composition of the mold flux was also attained from this experimental study.

Surface tension and interfacial tension

Zhang and the co-workers performed a modelling study on the surface tension of molten ionic systems[5]. The model was proposed on the basis of the so-called 'excess surface tension' σ^E to express the contribution of the non-linear interactions of the components. The surface tension, σ, in a molten binary slag can be evaluated using the expression

$$\sigma = \sigma^I + \sigma^E \quad [5]$$

and

$$\sigma^I = \sum x_i \sigma_i \quad [6]$$

where x_i and σ_i respectively indicate the mole fraction and surface tension for component i. The formula for excess Gibbs energy of mixing in a binary solution by Redlich and Kister has been borrowed to evaluate σ^E, i.e.:

$$\sigma^E = x_1 x_2 \left[A_o + A_1(x_1 - x_2) + A_2(x_1 - x_2)^2 \right] \quad [7]$$

where A_0, A_1, A_2 are the interaction coefficients independent of composition, and have an approximate linear relationship with temperature.

$$A_j = A_{j,o} + A_{j,1}T \quad j = 0,1,2 \quad [8]$$

The parameters $A_{j,0}$ and $A_{j,1}$ can be determined by optimizing a limited amount of experimental data of the melt. The calculated results indicate that the linear relation in Equation [8] is valid if the temperature range is less than 400°C. Figure 4 and Figure 5 illustrate that the model evaluated data give satisfactory agreements with the experimental results[6–7]. Figure 4 shows the surface tension evaluated for the Al$_2$O$_3$-Cr$_2$O$_3$ system between 2475 and 2620 K. In this system, however, the parameters A_1 and A_2 are equal to zero, indicating the behaviour of the melt similar to a regular solution. While the calculated surface tension for the CaO-Fe$_2$O$_3$ system at 1723 K depicted in Figure 5 shows two inflection points, indicating that all the

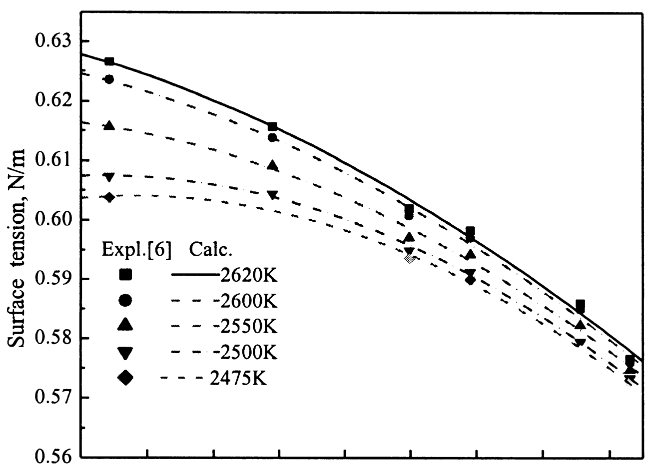

Figure 4. Calculated surface tension of Al$_2$O$_3$-Cr$_2$O$_3$ system between 2475 and 2620 K

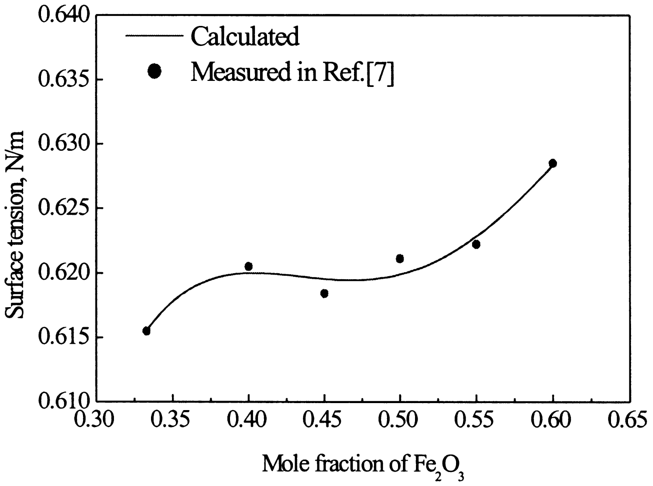

Figure 5. surface tension of CaO-Fe_2O_3 system at 1723 K

parameters in Equation [7] are not equal to zero. It can be seen from the phase diagram of CaO-Fe_2O_3, the compound $CaO{\cdot}2Fe_2O_3$ is within the composition range shown in Figure 5, and the temperature is very close to the melting point of the compound. The two inflections in Figure 5 may reflect the ordering tendency of the melt.

Kang, L.T. and co-workers[8] calculated the interfacial tension between the molten slag and nickel matte of the nickel flash furnace in the Jinchun Smelter, China. The Girfalco-Good model[9] was applied for the calculation, and the nickel matte was treated as a Ni_3S_2-Cu_2S-FeS ternary system with the composition of x_{Ni3S2} = 0.38, x_{Cu2S} = 0.10, x_{FeS} =0.52. Figure 6 is the calculated interfacial tension (γ) versus the surface tension (σ) of the molten slag in the furnace at temperatures of 1350, 1400 and 1500°C. The slag was treated as a 'FeO'-MgO-SiO_2 ternary system. The mass percents of the components 'FeO', MgO and SiO_2 in the slag were 54.90%, 7.72% and 37.38% respectively. The surface tension of the slag was obtained by regressing data measured by Narottam *et al.*[10]. Figure 6 shows clearly the variation trend of the slag-matte interfacial tension with the surface tension of the slag.

Conductivity

Recent investigations indicated that the electron or electron hole immigration in slag might become the rate-controlling step for the reactions between liquid metal and slag[11–12]. The measures promoting the immigration of electrons and/or electron holes across the metal-slag interface can increase the reaction rate between the metal and slag phase. Lu and co-workers measured the electronic conductivity of the CaO-SiO_2-Al_2O_3-FeO-Fe_2O_3 system between 1300–1400°C using the Wagner polarization technique[13]. In the slag systems, the mass ratio, $CaO/SiO_2/Al_2O_3$ kept 50:40:10. The contents of FeO and total iron oxides were 16.20% and 18.86% respectively for Slag 1, and 10.40% and 10.70% for Slag 2. The results show that electronic conductivity of the slags consists of free electron and electron hole conductivity. With the increasing temperature, the free electron conductivity decreases, while the electron hole conductivity increases; meanwhile Fe^{3+} appears a to be reduced to Fe^{2+}. The two conductivities are both related to the content of Fe^{3+} and Fe^{2+}. Figure 7 illustrates the dependence of the electronic conductivity on the molar ratio of Fe^{3+} to (Fe^{2+}+ Fe^{3+}) at 1400°C, showing a maximum at $x_{Fe^{3+}}/(x_{Fe^{3+}}+x_{Fe^{2+}})$= 0.27. The electronic conductivity is within the range of 10^{-4}–10^{-2} S.cm^{-1}. Compared with the ionic conductivity of the slag, the electronic conductivity can be neglected.

Slag chemistry and slag-metal reactions

In the west Sichuan province of China, there is a rich mineral resource of magnetoilmenite containing about 41% iron (data converted from the contents of all the iron oxides), 10% TiO_2, 0.2–0.3% V_2O_5. In the Panzhihua Iron and Steel Company, the magnetoilmenite concentrate is used as the raw material for iron making. In the blast furnace slag there, the TiO_2 content may reach 25–30%. In order to optimize the operation, and to comprehensively utilize the mineral resource, it is necessary to know the behaviour of the titanium oxides in the slag. Xue and the co-workers[14] carried out an experimental study on the equilibrium between Ti^{+3} and Ti^{+4} in molten CaO-SiO_2-TiO_2-Al_2O_3-MgO slag. The experiments were performed in a three-phase system containing H_2O-H_2 gas mixture, molten copper alloy (with small silicon and titanium contents) and slag. The TiO_2 content in the molten slags was varied from 11% to 40%. During the experiments, the molten slag was held in an alumina crucible with molybdenum lining. Three levels of the partial oxygen pressure and two temperatures, 1550°C and 1600°C were chosen for the investigation. TiO in the slag at the experimental conditions was considered very small, and it could be reasonably converted to the equivalent amount of Ti_2O_3. The following equilibrium may take place:

$$2\left(Ti^{3+}\right)+(1/2)O_2=2\left(Ti^{4+}\right)\,O^{2-} \qquad [9]$$

Figure 7 demonstrates the relationship between ($\%Ti^{4+}$)/[($\%Ti^{3+}$)+($\%Ti^{4+}$)] and the basicity, ($\%CaO$)/($\%SiO_2$), at 1550°C. It is seen that ($\%Ti^{4+}$)/[($\%Ti^{3+}$)+($\%Ti^{4+}$)] linearly increases with basicity in the range of ($\%CaO$)/($\%SiO_2$) <2, while above this range, ($\%Ti^{4+}$)/[($\%Ti^{3+}$)+($\%Ti^{4+}$)] may remain unchanged. The authors explained that the concentration of the free oxygen ions in the slag could be increased with the basicity when it was less than two, and be saturated in the slag above this range. At 1600°C, the variation with the basicity shows a similar tendency as that at 1550°C, however, ($\%Ti^{4+}$)/[($\%Ti^{3+}$)+($\%Ti^{4+}$)] could be slightly lower than that at 1550°C.

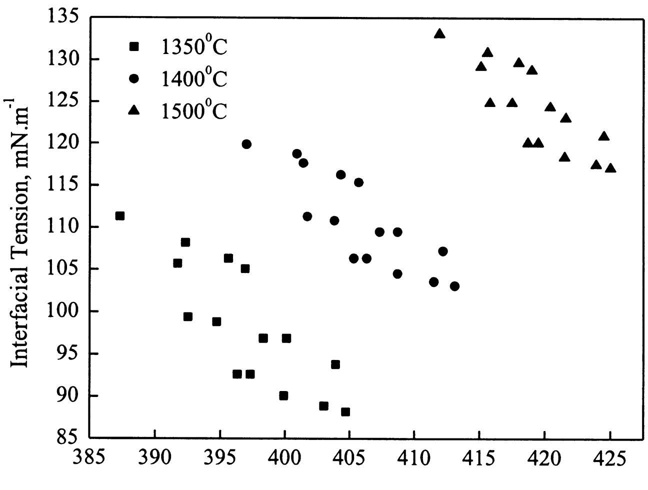

Figure 6. Relationship of interfacial tension between molten slag and matte with surface tension of slag. Surface tension, mN•m^{-1}

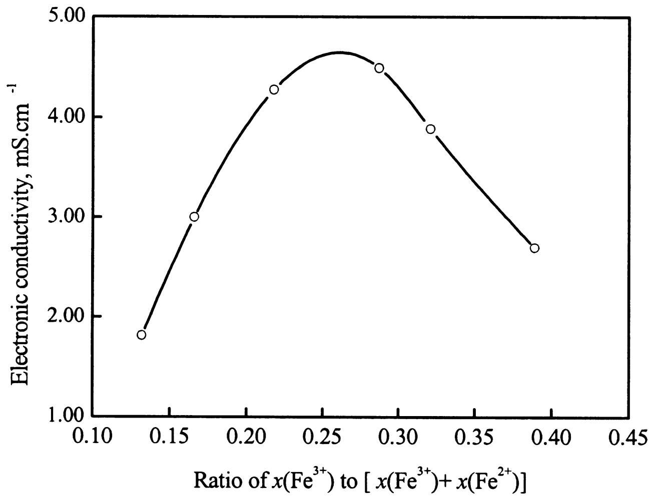

Figure 7. The relationship of electronic conductivity with $x_{Fe^{3+}}/(x_{Fe^{3+}} + x_{Fe^{2+}})$ at 1400°C

In another experimental study by the authors[15], the equilibrium between Cr^{2+} and Cr^{3+} in CaO-SiO_2-Al_2O_3-MgO-Na_2O-CrO_x was investigated at 1400°C and 1500°C and in a partial oxygen pressure range of 10^{-10} to 10^{-14} MPa. The matrix-slag composition data are listed in Table I. CrO_3 was added to the matrix-slag forming the slag samples containing CrO_3, 5%, 8% and 12% (mass) respectively.

The results have shown the existence of Cr^{2+} and Cr^{3+} in the molten slags, with almost no Cr^{+6} there. The following reaction between slag and gas phase may take place:

$$\left(Cr^{+2}\right)+(1/4)O_2=\left(Cr^{+3}\right) \quad [10]$$

The result indicates that the logarithm of $x_{Cr^{2+}}/x_{Cr^{3+}}$ is linearly increased with -lg p_{O_2}. Figure 8 demonstrates such a relationship obtained at 1673 K and if (%CaO)/(%SiO_2) is to be unity. It is also seen that $x_{Cr^{2+}}/x_{Cr^{3+}}$ increases with the total content of chromium oxides, while slightly decreasing with the basicity.

Wang carried out an experimental study on the equilibrium between molten silicon alloy and the CaO-SiO_2-Al_2O_3 system at 1550°C[16]. The experimental result has shown the increase of the aluminum content in the silicon alloy with the alumina content in the slag, and the same tendency for the calcium content in the alloy with calcia in the slag. Two major differences exist between their work and those by Weiss *et al.*[17]. First, Al_2O_3 content in the work by Wang covers a wider range up to 40.86%. Second, if the silica content is less than 50%, the increasing tendency mentioned above appears more obviously, though above this silica content, the results of the two studies are in an agreement.

Slags in steel making

The research on slags has been promoted by some recently developed and widely applied techniques in ferrous metallurgy. In steel production, the slag glazing on the refractory lining in the period from steel taping to the hot metal input of the following heat is an important technique among others. About 90% of the total steel production in 2002 in China used the slag splasing treatment, reducing the cost of production without lowering the steel quality[18]. The applications of the technique covered various steel grades, larger[19] and middle capacities of BOF, and top and bottom blown converters[20–21]. The campaign life has been greatly prolonged, up to 22766 heats for top and bottom blown converters[20–21]. Nearly 80 publications reported the technological efforts, their metallurgical effects as well as the relevant studies on slag from China's steel-making industry during the last three years. The contents of the studies involved the composition, fluidity and viscosity of the slag in the final stage before taping, suitable additive agents for the slag splasing treatments, and the splasing layer structure. Industrial trials and relevant investigations have also been performed in the Panzhihua Iron and Steel Company[22] where the titanium bearing magnetoilmenite concentrate has to be used.

According to a recent survey, there have been 64 reports related to the hot metal pretreatments, 53 to the external refining of liquid steel, and about 40 dealing with refining techniques on clean steel, involving IF steel since, June 2000. The applications of the technological measures have promoted the research on the refining slag[23–26].

Refractory erosion by molten slag

To prolong the campaign life of a melting or refining unit and to develop newer refractory materials, one needs to consider the refractory erosion by molten slag. In addition to the efforts in prolonging the campaign life in metallurgical reactors in industry, many laboratory studies were carried out in recent years. This involved the erosion resistance studies of currently used refractory materials[27–28] as well as those of the newly developed high-temperature structure materials[29–30]. The erosion experiments[28] of alumina-magnesa castable by molten slag from 1450–1550°C has been studied through a static approach. The result shows the chemical reaction and diffusion

Table I
Composition of matrix-slag

%CaO	%SiO_2	%Al_2O_3	%MgO	%Na_2O
22.5	37.5	20.0	10.0	10.0
30.0	30.0	20.0	10.0	10.0

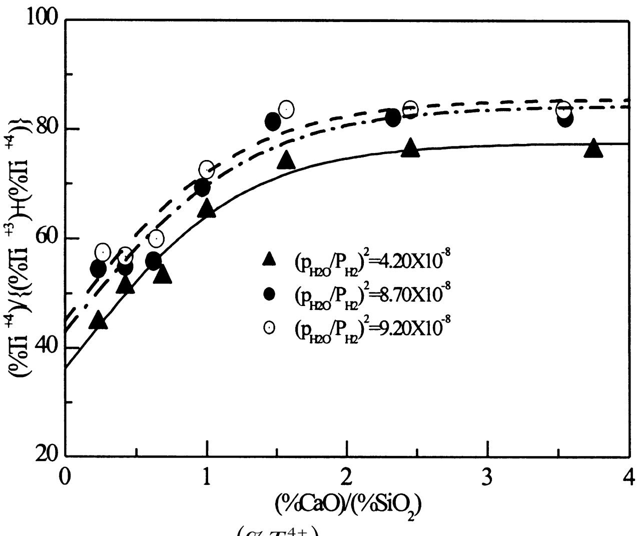

Figure 8. $\frac{\left(\%T_1^{4+}\right)}{\left(\%T_1^{3+}\right)+\left(\%T_1^{4+}\right)} vs\left(\%CaO/\%SiO_2\right)$ in molten CaO-SiO_2-TiO_2-Al_2O_3-MgO slag at 1550 °C

controlling mechanism, and the reaction of calcia in slag with alumina forming $CaO \cdot Al_2O_3$ in the interface between the molten slag and the tested material, therefore inhibiting further slag erosion. The apparent activation energy of the erosion obtained is as much as 424.8 $kJ.mol^{-1}$. In developing a new composite material, O´-Sialon/ZrO_2 (Sialon is a solid solution material in the Al-Si-O-N system), by BaO and co-workers[30], the experiments showed a better resistance to the erosion by the mold flux of continuous casting. The existence of zirconia that has very small solubility in the silicate melt may prevent O´–Sialon from reacting with dissolved carbon monoxide and other component in the mold flux.

Comprehensive utilization of slag

The metal value recovery from waste slags has received very close attention in China. This is mainly due to the complex chemical composition of the ores in some mines. For instance, in Panzhihua, the magnetoilmenite contains iron and titanium, and a small amount of vanadium as well. In Baotao, Inner Mongolia, the iron ore contains niobium and rear earth elements. This requires finding the way to extract the iron, and other metal values comprehensively. On the other hand, our metallurgists are also facing tasks recovering the metal values from the waste slags.

Among the efforts in these areas, the recovery of titanium from the waste blast furnace slag in Panzhihua appears to be pronounced. A group of authors proposed a heat treatment approach to enrich the titanium in the waste blast furnace slag that contains about 25% titania[31–32]. The first step of the treatment is to heat up the solid slag and maintain it at 1500°–1550°C and then to lower the temperature very slowly[31]. It was observed that the perovskite ($CaO \cdot TiO_2$, the titanium-richer phase in the solid slag) crystal grains grew, and more titania from other mineralogical phases was dissolved in the perovskite. The technique has been favorable for separating titania from the slag by gravity or flotation separations[32].

The techniques of recycling waste slag from blast, BOF and other metallurgical units have been applied widely due to the increasingly strict environmental demand. In addition to utilizing the waste slag to produce common cement and bricks, a new trend has occurred. The waste slag has been used to prepare high performance cementitious materials[33], glass ceramic[34], as well as the high-temperature structure ceramics. For example, Wang and co-workers synthesized Ca-α-Sialon from blast furnace slag through a method of carbothermal reduction and nitridation[35].

The waste slag has also been utilized in wastewater treatment in the paper-making industry. The result shows that it is an effective way to insure the discharged water reaching the parameters in the environmental standard[36]. The slags containing oxides of alloying metals have been used to replace alloying agents in BOF operations[37].

Summary

The present paper reviews publications on the slag-related research in China in the last three years. In the fundamental aspects, physical property predictions and measurements, slag-metal reactions, as well as the refractory erosion received close attention. Some representative studies in these areas have been described in this paper. The slag-related publications in various treatments for clean steel production and the utilization of the waste slags have been increasing remarkably since 2000. Those studies directly linked with industry have also been briefly reviewed.

References

1. ZHONG, X.M. The study on viscosity of multi-component melts, Doctoral dissertation, Department of Physical Chemistry, Metallurgical Engineering School, University of Science and Technology Beijing, March, 2003. (In Chinese).
2. Mills, K.C., *N. P. L. Report Che*., 1997, p. 65.
3. MALKOV, N.V., ROSHCHIN, V.E., and GANULLIN, A.A. Viscosity of slag melts of the 'CaF_2-SiO_2 —oxides of Rare-Earth elements' system. *Ferro-metallurgy*, 1986, vol. 4 (In Russian) pp. 31–34.
4. LIU, C.J. and JIANG, M.F. Viscosity and crystallization temperature of CaO-SiO_2-Na_2O -CaF_2-Al_2O_3-MgO system, *J. Northeastern University*, 2002, vol. 23, no. 7 pp. 656–659.
5. ZHANG, J.Y., SHU, Q.F., and WEI, S.K. Prediction of Surface Tension in Molten Metallic and ionic Systems, *Proc. vol. 2, Mills Symp., Metals, Slags, Glasses: High Temp. Properties & Phenomena*, 22–23 Aug. 2002, The Institute of Materials, London pp. 533–543.
6. ANISIMOV, S., GRITS, E.F., and MITIN, B.F. *Inorgan. Mater*., 1977, vol. 13 p. 1168. (In Russian)
7. SUMITA, S., MORINAGA, K., and YANAGASE, T. *J. Japan. Inst. Met*., 1983, vol. 47, no. 2 (In Japanese). pp. 127–131.
8. KANG, L.T., CAO, Z.M., WU, S.M., and QIAO, Z.Y. Interfacial Tension between Smelting Slag and Matte in Jinchuan Nickel Flash Furnace, *J. Univ. Sci. & Tech. Beijing*, 2002. vol. 24, no. 3 (In Chinese) pp. 123–128.
9. GIRFALCO, L.A. and GOOD, R.J. A Theory for the estimation of Surface and Interfacial energies, *J. Phys Chem*.,1957, 61:904.
10. NAROTTAM, P., BANSAL, R., and DOREMUS, H. *Handbook of Glass Properties*, Orlando, Academic Press Inc, 1986, 117.
11. KRISHNA-MURTHY, G.G., HASHAM, A., and PAL, U.B. Reaction rate of FeO in CaO-SiO_2-Al_2O_3-x slags by Fe-C droplets, *Ironmaking & Steelmaking*, 1993, vol. 20, no. 3. pp. 191–200.
12. LU, X.G., LI, F.S., and LI, L.F. *et al*. Electrochemical characteristic of decarburization reaction, *J. University of Science and Technology Beijing* (English ed.), vol. 6, no. 10, 1999. pp. 27–30.
13. LU, X.G., DING, W.Z., and LI, F.S. *et al*. Study of electronic conductivity of molten slags with Wagner polarization technique, *Acta Metallurgica Sinica*, 2001, vol. 37, no. 2. pp. 184–188.
14. XUE, X.X., DUAN, P.N., and LI, Z.P. Redox equilibria between Ti^{+3} and Ti^{4+} in CaO- SiO_2-TiO_2-Al_2O_3-MgO slags, *Acta Metallurgia Sinica*, vol 36, no. 11, 2000. (In Chinese) pp. 1172–1175.
15. CHEN, S.H., YANG, J., and XUE, X.X. *et al*. Redox equilibrium chromium oxides in CaO-SiO_2-Al_2O_3-MgO-Na_2O-CrOx slags, *The Chinese J. of Nonferrous Metals*, vol. 13, no. 1, 2003. pp. 255–258.
16. WANG, X.G., DING, W.Z., and TANG, K. *et al*. Experimental thermodynamic research on equilibrium between silicon alloy and CaO-SiO_2-Al_2O_3 melt

Trans. Nonferrous Met. Soc. China, vol. 11, no. 4, 2001. pp. 535–539.

17. WEISS, T. and SCHWERDFEGER K. Chemical equilibria between silicon and slag melts, *Metallurgical and Materials Transactions B*, vol. 25, no. 8, 1994.: pp. 497–504.

18. WONG, Y. Internal report in the Annual Meeting of Chinese Society for Metals, 2003—Beijing 17–19 April 2003. (In Chinese).

19. LUO, G. The design and pursuance of the automatic control system for the slag glazing operation of LD converter with a capacity of 250t, *Engineering Construction and Design*, vol. 4 2002. pp. 33–36.

20. Center of Science and Techniques of Wuhan Iron & Steel Company, A communication: The slag splashing technique in top and bottom combined blown Converters in Wuhan Iron & Steel Company, *J. Iron and Steel Research*, vol. 14, no. 2, 2002. p. 17.

21. XU, J. and TONG, P. Effects of long service campaign for combined blown converter under slag splash condition, *Steel Making*, vol. 18, no. 3, 2002. pp. 6-8,14. (In Chinese).

22. WEN, Y. Study of melting property of converter slag bearing V_2O_5 and TiO_2, *Iron & Steel*, vol. 37, no. 9, 2002. 17-19,34. (In Chinese).

23. BAO LU, G., CHENG, G.G., and SONG, B. *et al.* Oxidizing capability of refining slags containing BaO, *Journal of University of Science and Technology Beijing: Mineral Metallurgy Materials* vol. 7, no. 4, 2000. pp. 251–255.

24. ZHAO, J.X., FU, J., and WANG, P. Test of oxidizing dephosphorization for stainless steel using BaO-CaO slag series: *Special Steel*, vol. 23, no. 4, 2002. p. 20. (In Chinese).

25. WANG, Y.N., ZHU, R., and LI, S. Q *et al.* Effect of refining slag compounding on desulphurization of extra low sulphur steel: *Special Steel*, vol. 23, no. 2, 2002. p. 17. (In Chinese).

26. LI, G.R. and WANG, H.M. Effect of Li_2O on dephosphorization of ladle refining slags CaO-SiO_2-MgO-Fe_2O_3-MnO_2 -P_2O_5, *Special Steel*, vol. 23, no. 14, 2002. p. 14. (In Chinese).

27. YUAN, Z.F., HUANG, W.L., and MUKAI, K. Local erosion of magnesia-chrome refractories driven by Marangoni convection at the slag-metal interface, *Journal of Colloid and Interface Science*, vol. 253, no. 1, 2002. pp. 211–216.

28. LI, Y.W., WANG, X D., and FU, Y.K., *et al.* Mechanism of slag erosion resistance for alumina-magnesia-castable, *Refractories*, vol. 36, no. 1, 2002. pp. 24-26. (In Chinese).

29. DENG, C.J., HONG, Y.R., and ZHONG, X.C. *et al.* Slag-resistance of MgAlON spinel, *Journal of University of Science and Technology Beijing: Mineral Metallurgy Materials*, vol. 7, no. 2, 2000, pp. 96–98.

30. BAO, H., ZHEN, Q., and LI, W.C. Anti-crosion of O'-Sialon/BN and O'-Sialon/ZrO_2 composites in molten steel and slag, *J. of University of Science and Technoogy Beijing*, vol. 23, no. 4, 2001. pp. 311–315.

31. LOU, T.P., LI, Y.H., and LI, L.S. *et al.* Study on kinetics of perovskite phase precipitate in slag bearing titanium: *Kuei Suan Jen Hsueh Pao/ Journal of the Chinese Ceramic Society*, vol. 28, no. 3, 2000. pp. 155–158. (In Chinese).

32. MA, J.W. and SUI, Z.T. Chen B C. Separating titania from treated slag by gravity separation or flotation, Transactions of Nonferrous Metals Society of China vol. 10, no. 4, 2000. pp. 520–523. (English Ed.).

33. HU, S.G., GUAN, X.M., and DING, Q.J. Research on optimizing components of microfine high - performance composite cementitious materials, *Cement and Concrete Research*, vol. 32, no. 12, 2002. pp. 1871–1875.

34. HAN, J.J. and ZHAO, X.J. Preparation of glass ceramic based on granulated slag and cullet, *Journal of Wuhan University of Technology*, vol. 16, no. 4, 2001. pp. 31–35.

35. WANG, F.M., LI, W.C., and GUO, Y.Y. *et al.* Synthesis of Ca-∝–Sialon from blast furnace slag by carbothermal reduction and nitridation (CRN), paper 163 in *Proceedings of Sixth International Conference on Molten Slags, Fluxes and Salts*, Stockholm, Sweden-Helsinki, Finland, 12–17 June, 2000. CD-ROM Version.

36. DENG, Y.X., XU, H., and ZHONG, Z.Y. Application of metallurgical furnace slags in waste water treatment, *Metal Mine*, vol. 3, 2002. pp. 42–44. (In Chinese).

37. FAN, Y.J., LIU, M.Z., and YANG, M.S. *et al.* 20MnSiV-making with direct alloying of V-slag in basic oxygen converter, *Iron and Steel*, vol. 36, no. 5, 2001. pp. 17–20. (In Chinese).