

Influence of Hot Metal Composition on Ar-1%Mg Gas-Metal Reaction in Magnesium Desulfurization Process

HAIPING SUN, YUNG-CHANG LIU and MUH-JUNG LU

*Iron and Steel Research & Development Department
China Steel Corporation*

The influences of oxygen [O], sulfur [S], carbon [C], silicon [Si], manganese [Mn] and phosphorus [P] in hot metal on the reaction of an Ar-1%Mg(g) bubble rising in the hot metal during desulfurization by granulated magnesium (Mg) injection were analysed by kinetic simulation. The increase in [O] decreases the Mg yield of the process. This study suggests that the Mg yield can be improved and the process time be shortened by the pre-deoxidation of the hot metal. The Mg(g) in gas is consumed by four routes: the dissolution into metal; desulfurization; deoxidation; and the remainder in bubbles. The variation of the fraction of the Mg(g) for each route with [O], [S] or [C] is significant, but that with [Si], [Mn] or [P] is marginal. The content of Mg(g) in the process offgas is lower in the earlier injection period, but it is higher and increases with decreasing [C] in the final injection period.

Keywords: Steelmaking, Desulfurization, Magnesium injection, Gas-metal reaction, Bubble

1. INTRODUCTION

Kinetic models describing an argon⁽¹⁾ or nitrogen⁽²⁾ bubble rising in hot metal during Mg injection have been developed by the authors. The influences of the types of carrier gas^(2,3), and of the Mg(g) content in gas on bubble behavior^(1,4) were discussed. These models were later combined with kinetic models for the hot metal reactions with Mg(g) bubbles⁽⁵⁾ and inclusions⁽⁶⁾, and mass and heat transport models for the injection lance^(7,8) and in the bath⁽⁹⁾. The combined models were successfully applied for the analysis of the process in practice⁽¹⁰⁾. In this report, the efforts were focused on the analysis of the influences of hot metal composition on the reactions of an Ar-1% Mg(g) bubble rising in a hot metal and on the Mg(g) loss in the offgas of a Mg injection process.

2. METHODS

During the Mg injection process, the Ar-Mg(g) bubbles that formed from the carrier gas and magnesium vapor vaporized from Mg granules at the lance tip react with the hot metal as the bubbles are rising toward to the bath surface. The operational conditions shown in Table 1 were used in the investigation of the effect of [O], [S], [C], [Si], [Mn] and [P] in the hot metal on the reactions of the bubbles. A typical BF hot metal composition was used as the reference composition; the

contents of the alloying elements were allowed to vary over the ranges shown in Table 1 for their sensitivity analysis. Since [S] in hot metal is changed during Mg injection, two typical hot metals were selected. One is called Metal I, which is the hot metal before or during the initial stage of Mg injection that contains no Mg and 300 ppm [S]; and the other one is called Metal F, which is the hot metal after or during the final stage of the Mg injection that contains 50 ppm [S] and the contents of Mg and O that are in equilibrium with 50 ppm [S]. A kinetic model⁽¹⁾ is applied to simulate the reactions of a bubble initially containing 1%Mg(g) rising from a depth of 3.5 m in these hot metals to the bath surface. The outcome of the simulation are the fractions of Mg(g) in the initial bubble that are consumed for the dissolution in hot metal as [Mg] (F_M), reacting with [S] as MgS (F_S), oxidation with [O] as MgO (F_O), and remainder in the gas bubble as Mg(g) (F_B) when the bubble reaches the bath surface.

3. RESULTS AND DISCUSSION

The physical and kinetic characteristics of an argon bubble rising in hot metal were investigated by the kinetic model⁽¹⁾. It was found that the physical characteristics, such as the rising velocity, residence time, volume and surface area of the bubble and the mass transfers in the vicinity of the bubble surface, are essentially unaffected by varying the metal composition

Table 1 Conditions for the investigation of effect of metal composition on the reaction of gas bubbles in magnesium desulfurization process

Description	Unit	Values	
Hot metal temperature	°C	1350	
Carrier gas	-	Argon	
Mg(g) in gas at lance tip	Vol%	1	
Depth of lance tip	M	3.5	
Ambient pressure	Atm	1	
Hot metal composition:		Reference composition	Range
Magnesium	ppm	0 or in eq. with [S]	
Sulfur	ppm	300	0.5 - 300
Oxygen	ppm	10 or eq. with [Mg]	0 - 60
Carbon	mass%	4.5	3 - 5.5
Silicon	mass%	0.5	0 - 1.4
Manganese	mass%	0.2	0 - 0.6
Phosphorus	mass%	0.1	0 - 0.6

within the range of interest. These aspects are therefore not discussed in this report. In general, the elements such as [C], [Si], [Mn] and [P] in hot metal are not directly involved in the Mg desulfurization. [O] is an exception because it directly oxidizes Mg. However, the interaction parameters⁽¹¹⁻¹³⁾ in Table 2 indicate that the activities of [Mg], [S] and [O] in hot metal are influenced by [C], [Si], [Mn] and [P], hence they would indirectly affect the Mg desulfurization. The interaction parameters of [Mg] with [Mn] and [P] are not available in open publications, and they are assumed to be zero in this work. Despite this assumption, simulations on the influences of [Mn] and [P] could show their true effectiveness on Mg desulfurization and are a subject to be reexamined in the future.

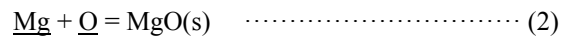
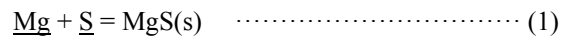
3.1. Oxygen

3.1.1. Effect of oxygen on equilibriums in hot metal

Oxygen in hot metal tapped from a blast furnace is dominated by either the reaction $\underline{C} + \underline{O} = \text{CO}$ or $\underline{\text{Si}} + 2\underline{\text{O}} = \text{SiO}_2$ in the hearth, depending on which reaction is faster than the other. Since the reaction $\underline{\text{Si}} + 2\underline{\text{O}} = \text{SiO}_2$ is strongly exothermic, [O] would be higher for higher tapping temperatures. [O] may further increase as the hot metal travels via the open systems of tap hole, rounder, and torpedo car before being poured into the ladle for Mg injection. [O] in a BF hearth was estimated to be about 10 ppm by thermodynamic calculation⁽¹¹⁾. In fact, [O] as high as 16 ppm was confirmed in

an analysis of re-melted BF iron by the authors.

The equilibrium relations between [S], [O] and [Mg] are obtained by following two reaction equations:



Mg desulfurization by Equation 1 is deteriorated by [O] in two ways. Firstly, as a parallel reaction, [O] oxidizes [Mg] by Equation 2 that reduces the amount of [Mg] available for desulfurization. Secondly, as indicated by the interaction parameters in Table 2, [O] reduces the activity coefficients of both [Mg] and [S], resulting in the solubility of MgS precipitation ([Mg][S]) being higher for higher [O].

[Mg] increases, and [S] and [O] decrease from Mg injection according to the equilibriums of Equations 1 and 2. The equilibrium relations between [S] and [Mg] in hot metal containing [O] and that without [O] are shown in Fig.1. Logarithmically, [S] decreases linearly with increasing [Mg] when [O] is absent in the hot metal as shown by dotted line. When [O] is present and its content is in equilibrium with [Mg], as given by the dashed line, [S] becomes higher and slightly deviates from the linear relationship as shown by the solid line. The V shape for [O] line (dashed line) is the result of the combination of two opposite effects of increasing

Table 2 Interaction parameters (e_j^i) in hot metal

j\i	Mg	S	O	C	Si	Mn	P
Mg	0	-	-1.61	0.15	-0.088	-	-
S	-	-0.046	-0.27	0.111	0.075	-0.026	0.026
O	-106	-0.133	-0.17	-0.421	-0.066	-0.021	0.07

[Mg] on [O]; the first one is to decrease [O] by Equation 2, and the second one is to increase [O] by the interaction between O and Mg atoms in hot metal. In practice, the V shape may not appear since there is no oxygen source for [O] pickup, and the [O] would vary in a way indicated by the arrow.

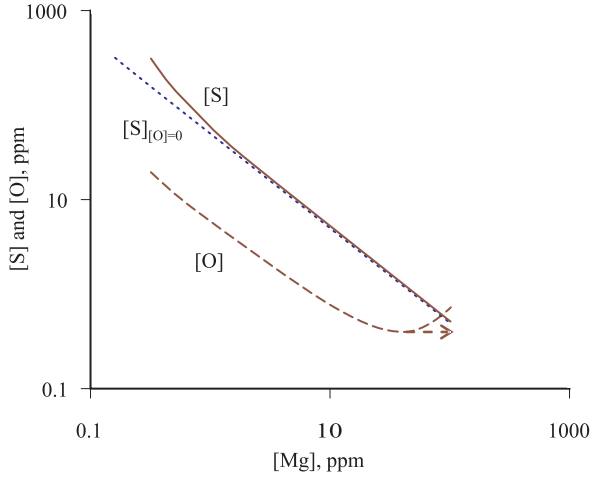


Fig.1. Equilibrium relations between [S], [Mg] and [O] in hot metal at 1350°C.

3.1.2. Effect of oxygen on Mg(g) consumption routes

The effects of [O], [C], [Si], [Mn] or [P] in Metal I on the consumption routes of Mg(g) in a bubble were simulated using the conditions in Table 1. The results are shown in Fig.2. The superimposed table shows the reference composition for Metal I that represents the hot metal before injection. The influence of an element was examined by varying the content of this element in the hot metal while keeping the contents of the others the same as the reference composition. For example, the broken-dotted lines show the effect of [O] on the fractions of Mg(g) in a bubble that are consumed via different routes during an Ar-1%Mg(g) bubble rising from 3.5 deep in the hot metal of a composition given by the superimposed table in Fig.2 except [O], which varies from 0 to 60 ppm.

When [O] is less than 7 ppm, the effect of [O] is not significant and over 90% of the Mg(g) in the gas bubble is consumed for desulfurization (F_S). When [O] is higher than 8 ppm, Mg(g) for deoxidation (F_O) increases sharply and that for desulfurization (F_S) decreases sharply by increasing [O]. When [O] is higher than 20 ppm, the majority of Mg(g) is consumed

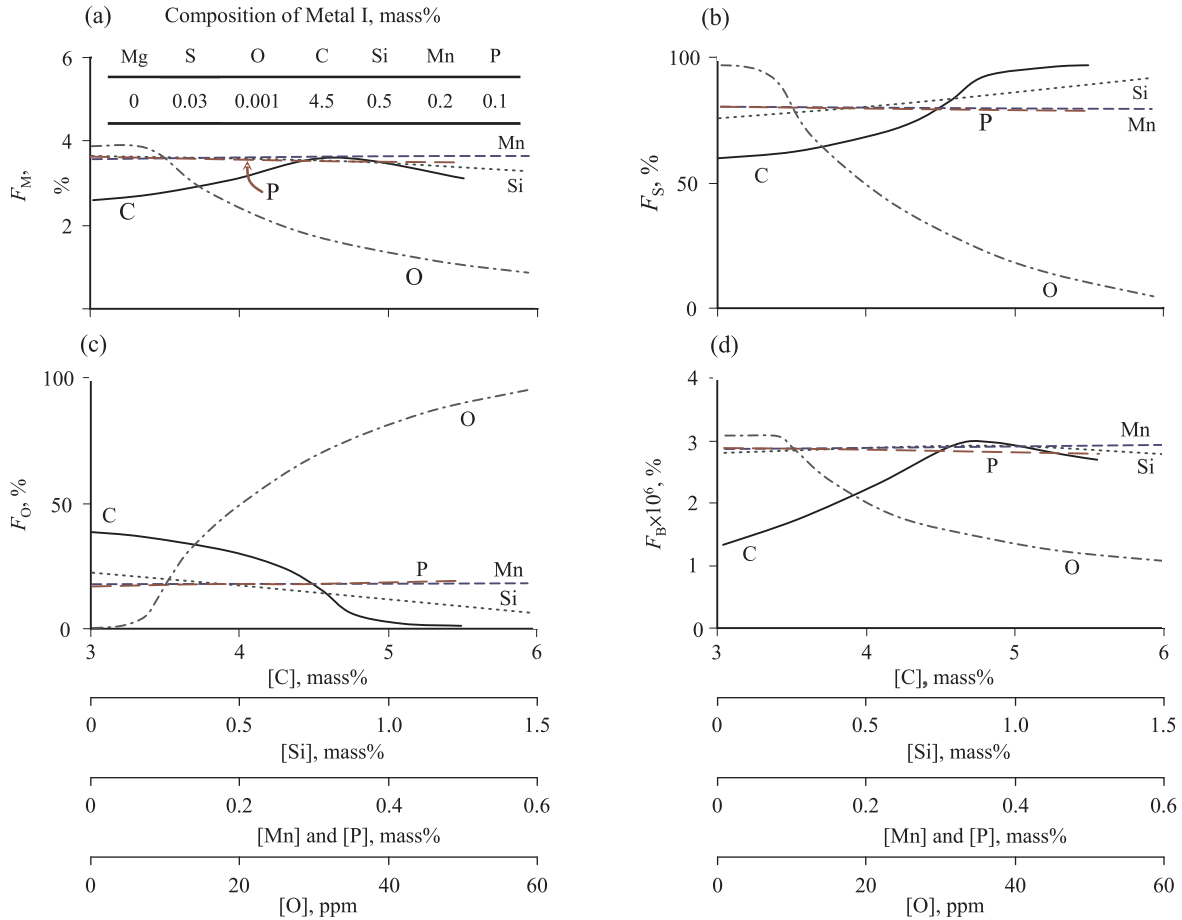


Fig.2. Effect of alloying elements on the fractions of Mg (g) in initial bubble that are dissolved in hot metal (F_M), reacted with [S] (F_S), reacted with [O] (F_O) and remaining in the bubble (F_B) during a bubble rising in Metal I at 1350°C.

for deoxidation even though [O] is still much lower than [S]. This indicates the preferential forming of magnesium oxide over sulfide and effective desulfurization occurs only when [O] is lower than 7 ppm. The fraction of Mg(g) remaining in the bubble (F_B) represents the loss rate of Mg(g) in the offgas of an injection process^(1,2,4). F_B is close to zero and it decreases with increasing [O].

The preferential oxidation of Mg was evidenced in practice by Visser and Boom⁽¹⁴⁾ using EBS/spot EDS images of the inclusion in the hot metal immediately after the initiation of Mg injection. MgO was found at the core and was surrounded by MgS at perimeter for the inclusion. Furthermore, the MgO was not found in the inclusions in the hot metal after post injection and deslagging. The most likely scenario for the formation of inclusions with MgO rich cores are that the Mg(g) in gas bubbles or [Mg] in hot metal is preferentially oxidized by [O] to produce MgO inclusions until the [O] is reduced to below 7 ppm. Later, these MgO inclusions serve as seeds for desulfurization to produce MgS which cocoons MgO seed. MgO was not found in the inclusions after the injection is simply because of the depletion of [O] in the metal.

The hot metal containing [Mg], [S] and [O] in Fig. 1 is used to emulate those in the initial ([S] >250 ppm), middle ([S]=250-80 ppm) and final stages ([S] =80-10 ppm) in an Mg injection process. The F_M , F_S , F_O , and F_B for a bubble rising to the bath surface were obtained

for the hot metal of [S] decreasing from 300 to 1 ppm. In Figure 3, the solid lines show the results obtained for the hot metal of [O] decreasing from 18.3 ppm, and the dashed lines show those for a hypothetical hot metal without [O]. Initially, F_M is kept low because Mg is more favored to react with [S] or [O] when either or both of them is/are higher allowing their fast mass transfer to the bubble surface. For the metal with [O], F_O is as high as 25% initially but decreases with injection time. For the metal without [O], F_M and F_S are increased by 10-20% throughout the injection process but F_B is essentially unaffected by the absence of [O]. Both broken-dotted lines in Fig.2 and the results in Fig.3 indicate that the Mg loss by oxidation and the decrease in Mg desulfurization could be significant even when [O] is lower. F_B or the Mg loss in offgas is marginally affected by [O]. The important implication is that, the process efficiency may be improved, and the process time may be reduced, if oxygen is removed from hot metal prior to the Mg injection. This agrees with the observation by Hiraga et al.⁽¹⁵⁾ that Mg yield increased by 4% and the process time was also shortened when the hot metal was pre-deoxidized by aluminum before feeding CaO-Mg wire.

3.2. Sulfur

Figure 3 also shows the effect of [S] on the Mg(g) consumption routes. For metal of higher [S] in the earlier injection period, most of Mg(g) is consumed by

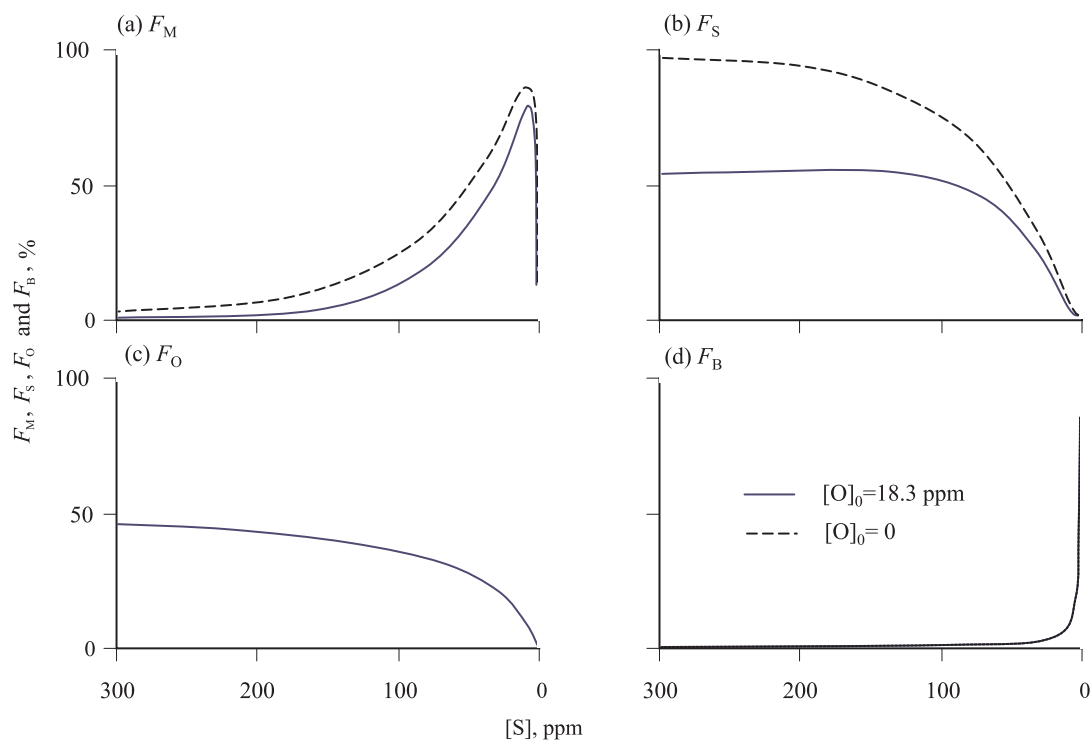


Fig.3. Changes of the fractions of Mg(g): (a) dissolved in hot metal (F_M); (b) reacted with [S] (F_S); (c) reacted with [O] (F_O); and (d) remained in bubble (F_B), after the bubble reaching bath surface.

desulfurization (F_S). For metal of lower [S] in the final stage, F_S becomes smaller, and F_M and F_B become larger. Larger F_B when [S] is lower also indicates the heavy Mg(g) loss in the offgas during the final injection process.

3.3. Carbon

3.3.1. Effect of carbon on equilibriums in hot metal

The variation of [C] in hot metal is considered to be within a narrow range because the [C] is close to the saturation level due to the presence of coke lumps in the hearth of a BF. Under the strong reducing conditions created by the Mg injection, [C] is not directly involved in the reactions. Indirectly, [C] affects the equilibrium relation between [Mg], [S] and [O] through changing their activities. For a known metal composition, the activities of [Mg], [S] and [O] are given by:

$$a_j = f_j [j] \quad \dots \dots \dots (3)$$

Where, a_j and f_j are the activities and activity coefficients, respectively; and j is [Mg], [O] or [S] in the hot metal, the value of f_j is obtained from the metal composition and the interaction parameters (e_j^i) in Table 2 by:

$$\log f_j = \sum e_j^i [i] \quad \dots \dots \dots (4)$$

Where, i indicates [Mg], [C], [Si], [Mn], [S], [P] or [O]. The solid lines in Figure 4 show the effect of [C] on the activities of [S] and [O] (a_s and a_o) in the metal before Mg injection (Metal I). [C] is varied from 3 to 5.5 mass% while the others are kept as those in the superimposed table. The a_s increases and a_o decreases with increasing [C] because e_s^c is positive and e_o^c is negative. During Mg injection, [Mg] and [O] that are in equilibrium with [S] in hot metal are obtained from the equilibriums of Equations 1 and 2 by:

$$[\text{Mg}]_{\text{EQ}} = \left(\frac{a_{\text{MgS}}}{K_1 [\text{S}]} \right) \frac{1}{f_{\text{Mg}} f_{\text{S}}} \quad \dots \dots \dots (5)$$

$$[\text{O}]_{\text{EQ}} = \left(\frac{K_1 a_{\text{MgS}} [\text{S}]}{K_2 a_{\text{MgO}}} \right) \frac{f_{\text{S}}}{f_{\text{O}}} \quad \dots \dots \dots (6)$$

Where, a_{MgO} and a_{MgS} are the activities of MgO and MgS, K_1 and K_2 are equilibrium constants for Equations 1 and 2 and their values as a function of temperature are given in reference⁽¹⁾. If [S] and the temperature are known, the values in brackets on the right hand sides of Equations 5 and 6 are constants since the activities of MgS and MgO are approximately unity. [Mg] and [O] are, therefore, dependent on f_{Mg} , f_{O} and/or f_{S} , which are, in turn, dependent on the metal composition according to Eqn. 4. For example, an increase of [C]

will affect [Mg] in three ways according to the Eqn. 5. The first one is to decrease [Mg] by increasing f_{Mg} due to the positive e_{Mg}^c . The second one is also to decrease [Mg] by increasing f_{S} due to the positive e_{S}^c . The last one is to increase [O] by increasing f_{S} and decreasing f_{O} due to the positive e_{S}^c and negative e_{O}^c ; and the increase in [O], in turn, reduces f_{Mg} due to the negative e_{O}^c that increases [Mg]. The solid lines in Figure 5 show the effect of [C] on the equilibrium contents of [Mg] and [O] in the hot metal of 50 ppm [S] (Metal F). As a result of the combined three effects, the [Mg] is decreased with increasing [C] particularly when the latter is below 4.5 mass%. [O] also increases with the increasing [C].

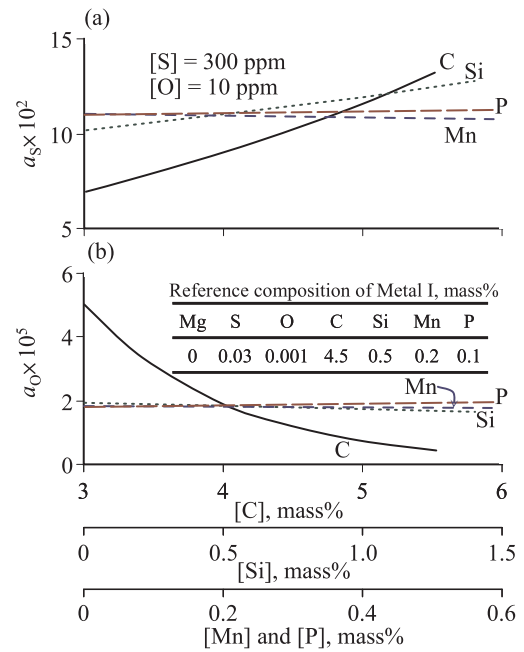


Fig.4. Effect of elements on activities of sulfur and oxygen in hot metal before Mg injection (Metal I).

3.3.2. Effect of carbon on Mg(g) consumption routes

For a bubble rising in Metal I in the initial stage of Mg injection, F_M , F_S , F_O , and F_B as a function of [C] are shown by the solid lines in Fig.2. [C] was allowed to vary over a wide range from 3 to 5.5 mass% while the contents of the other elements were kept as those in the superimposed table. Most of Mg(g) in the bubble is consumed for desulfurization (F_S) and deoxidation (F_O) during the bubble's rise. Since the activity of sulfur increases and that of oxygen decreases with increasing [C], the F_S is increased but the F_O is decreased. The F_M is lower than 4%, and it initially increases and then decreases mainly because of the changes in the share of Mg(g) consumed by other routes. Since Mg is absent in Metal I, F_B is close to zero.

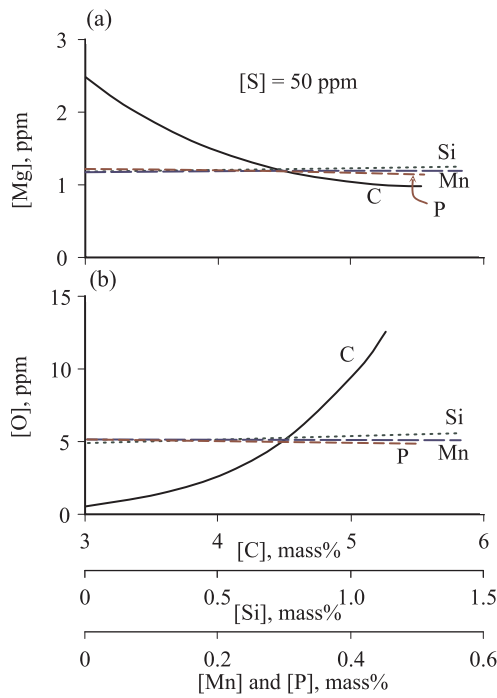


Fig.5. Effect of elements on the equilibrium contents of Mg and O in hot metal (Metal F) containing 50 ppm [S] in final stage of Mg injection at 1350°C.

For Metal F, when the Mg injection comes to its final stage, the [S] is about 50 ppm, and the [Mg] and [O] in Metal F are assumed to be in equilibrium with the [S] but vary with [C] as seen by the equilibrium relations indicated by the solid lines in Fig.5. These equilibrium relations were used to investigate the effect of [C] on the consumption routes of Mg(g) in a bubble during the final stage of Mg injection. The results are given by the solid lines in Fig.6. F_M , F_S and F_B all decrease while F_O increases with the increasing [C]. The higher [O] as seen by the solid line in Fig. 5b is responsible for the increase in F_O , which in turn reduces the other three.

3.4. Silicon

3.4.1. Effect of silicon on equilibriums in hot metal

The [Si] is mainly dependent on, and increases with increasing, the temperature of the BF hearth. [Si] is not directly involved in Mg desulfurization, but the activities of, and the equilibrium relation between, [Mg], [S] and [O] in the reaction system is affected by [Si]. The effect of [Si] on a_S and a_O in Metal I are shown by dotted lines in Fig.4. For the metal of given contents of both [S] and [O], the activity of [S] increases and that of [O] decreases with increasing [Si]. This is because the interaction parameter of [Si] with

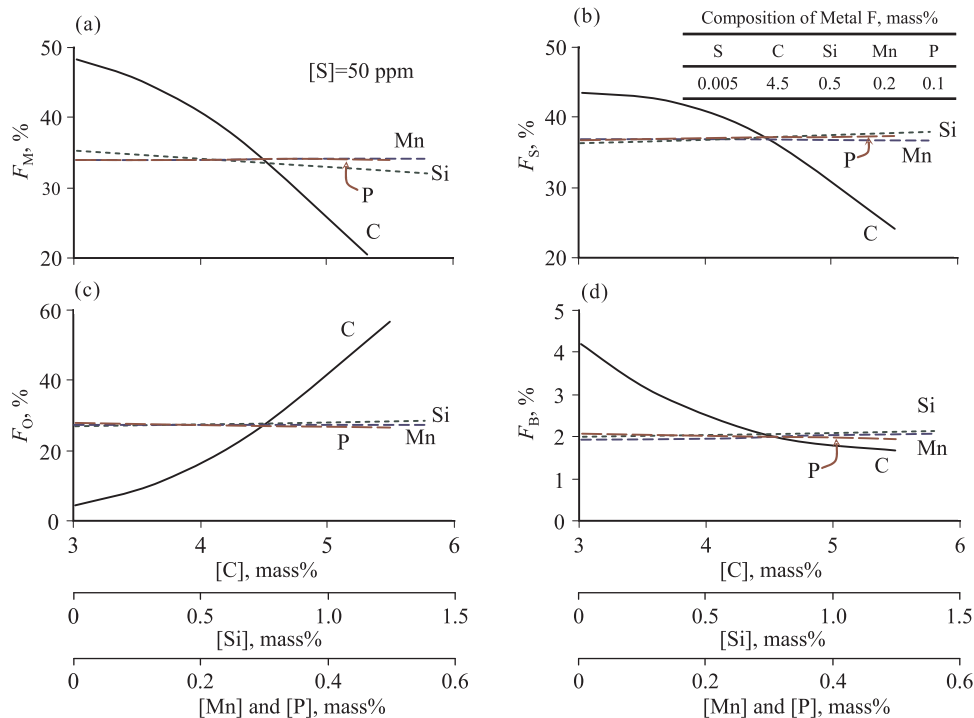


Fig.6. Effect of alloying elements on the fractions of Mg(g) in an argon bubble that are dissolved in hot metal (F_M), reacted with [S] (F_S) and [O] (F_O), and remained in bubble (F_B) after the bubble reaching bath surface in final period of Mg injection process at 1350°C.

[S] is positive and that with [O] is negative (Table 2). The dotted lines in Fig.5 show the effect of [Si] on the [Mg] and [O] which are in equilibrium with 50 ppm [S] in Metal F. Similar to the effect of [C], [Si] also has an effect on [Mg] or on [O] through three ways. An increase in [Si] slightly increases both [Mg] and [O]. Adding [Si] increases a_S to reduce [Mg] through Eqn. 1, but it also reduces f_{Mg} and f_O to increase [Mg] and [O] contents. The slight increase in [Mg] and [O] with increasing [Si] is the result of the combination of these effects.

3.4.2. Effect of silicon on Mg(g) consumption routes

The dotted lines in Fig.2 show the effect of [Si] on the consumption routes of Mg(g) in a bubble traveling in Metal I. An increase in [Si] increases F_S and decreases F_O since the activity of [S] is increased and that of [O] is decreased. The dotted lines in Fig.6 show the effect of [Si] on the consumption routes for the Metal F of the composition given by dotted lines in Fig.5. The increase in F_S is mainly attributed to the increase in sulfur activity and the increase in F_O is attributed to the increase of [O] by adding [Si]. Any increase in F_S or F_O in turn decreases F_M . The slightly higher [Mg] for the metal of higher [Si], as shown by the dotted line in Fig.5a, reduces the Mg(g) dissolution rate, which also contributes to the decrease in F_M and the increase in F_O .

Considering that [Si] in BF metal usually varies in a narrow range between 0.3 and 0.6%, its effect on the Mg(g) consumption routes would not be as significant as those shown in Figs.2 and 6 where [Si] was intentionally widely varied. However, if burnt lime is also added into the injectant, for example when injecting the Mg-CaO mixture, the desulfurization would also be via the reaction $2CaO + \underline{S} + \frac{1}{2}\underline{Si} = CaS + \frac{1}{2}2CaO \cdot SiO_2$ in which silicon is involved as a reactant. Hence, the effect of silicon should be reassessed when CaO is present.

3.5. Manganese

3.5.1. Effect of manganese on equilibriums in hot metal

The effects of [Mn] on the activities of [S] and [O] in Metal I are shown by dashed lines in Fig.4. Since both the interaction parameters of [Mn] with [S] and that with [O] are negative, the activities of [S] and [O] are slightly reduced by the increase in [Mn]. For Metal F, the effect of [Mn] on [Mg] and [O] are shown by the dashed lines in Fig.5. Both [Mg] and [O] are essentially unaffected by [Mn] since the examined [Mn] range is too narrow to pose a significant effect on the equilibriums between [Mg], [S] and [O].

3.5.2. Effect of manganese on Mg(g) consumption routes

As shown by the dashed lines in Fig.2 for Metal I and in Fig.6 for Metal F, the fractions of Mg(g) consumption are essentially unchanged by varying [Mn]. This is because [Mn], over the examined varying range, only marginally affects the chemical properties of [Mg], [S] and [O] in Figs.4 and 5. Although the direct [Mn] desulfurization through $[Mn] + [S] = MnS$ is not expected thermodynamically, there may be a thermodynamic condition for [Mn] desulfurization when [Mg] is present in the hot metal. As MgS particles in the hot metal after Mg injection was found to be enriched with manganese⁽¹⁴⁾, the [Mn] may enhance the Mg desulfurization by forming (Mg,Mn)S solid solution. Hence, the effect of [Mn] on the Mg desulfurization deserves to be further explored.

3.6. Phosphorus

3.6.1. Effect of phosphorus on equilibriums in hot metal

As shown by the broken lines in Fig.4, the activities of [S] and [O] are slightly increased by the increase in [P] since the interaction parameters of [P] with [S] and [O] are positive and of small magnitudes. For Metal F that contains [Mg] and [O] in equilibrium with 50 ppm [S], [Mg] and [O] are slightly reduced by increasing [P] as shown by broken the lines in Fig.5.

3.6.2. Effect of phosphorus on Mg(g) consumption routes

The broken lines in Fig.2 for Metal I, and in Fig.6 for Metal F show that the consumption routes for Mg(g) in a bubble rising in the two metals are essentially unchanged when [P] is varied.

3.7. Effect of alloying elements on magnesium vapor loss in off gas

For a metal of a given composition, the Mg(g) content in the process offgas is obtained from the Mg(g) remaining in the argon bubbles that arrive at the bath surface (F_B). Once the Mg(g) content in the offgas is known, the loss rate of Mg(g) in the offgas is simply obtained by the amount of gas traveling through the hot metal, the latter can be approximated by the injecting gas flowrate. The small F_B in Fig.2 for Metal I suggests that the Mg loss rate in the initial injection period was satisfactorily low, which means that the effect of alloying elements is unimportant. For Metal F in the final injection period, the Mg loss rate in the offgas is shown in Fig.7, which is obtained using the injection gas flowrate given in Table 1 and F_B value in Fig. 6d. The variation of the Mg loss rate was found to be unnoticeable when varying [Si], [Mn] and [P] but the loss rate

decreased with increasing [C]. This is because F_B , as previously shown in Fig. 6d, does not change significantly when varying the elements except [C], but it markedly decreases with increasing [C]. As mentioned before, [C] in hot metal is close to the saturation level and its variation is limited to a narrow range. Hence the effect of [C] on the Mg loss in the offgas may not be important in practice either.

Finally, it is worthwhile to note that, since there is no data available for the interaction parameters of [Mg] with [Mn] or [P], these parameters were assumed to be zero when the effects of [Mn] and [P] were examined. The simulation accuracy, which relied heavily on the accuracy/availability of the interaction parameters, will be improved when these parameters are upgraded/ provided in the future.

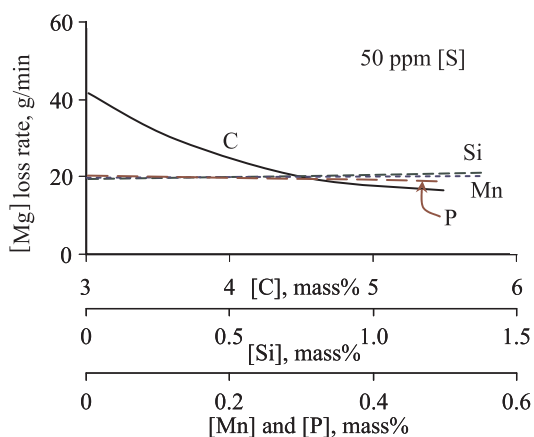


Fig.7. Effect of elements in hot metal on Mg loss rate via offgas in final stage of Mg injection at 1350°C.

4. CONCLUSIONS

The effects of the composition of the hot metal on the reaction of an Ar-1%Mg(g) bubble rising in the hot metal and Mg(g) loss rate in offgas of a Mg injection process were investigated in this work.

For an Mg injection, [O] in the hot metal was found to be responsible for Mg loss by oxidation. The Mg yield and the process speed could be deteriorated when [O] is higher. The fraction of Mg(g) in gas for desulfurization decreases as [S] decreases during Mg injection. In initial Mg injection period, the dissolution of Mg(g) from bubbles into the hot metal is decreased with an increasing [O], but it is initially increased and then slightly decreased with an increasing [C]. The fraction of Mg(g) in gas for desulfurization increases but that for deoxidation decreases with increasing [C] and [Si] or with decreasing [O]. The Mg(g) remaining in the gas at the bath surface, or the Mg loss rate in

offgas, is low, and the effect of alloying elements on the Mg loss rate is insignificant. In the final Mg injection period, Mg(g) dissolved into hot metal, reacted with [S] and remaining in an argon bubble arriving at bath surface decrease while that reacted with [O] increases with increasing [C]. The effects of other elements are insignificant. The Mg loss rate in off gas decreases with increasing [C].

REFERENCES

1. H. Sun, Y.C. Liu and M.J. Lu: Steel Research International, 80 (2009), 3, pp. 199-207.
2. H. Sun and Y.C. Liu: Journal of Chinese Society of Mechanical Engineers (JCSME), accepted in 2012 for publication .
3. H. Sun, Y.C. Liu and M.J. Lu: ISIJ International, Vol. 49, 2009, No. 6, pp. 771-776.
4. H. Sun, Y.C. Liu and M.J. Lu: Aist Transaction, Iron & Steel Technology, 6 (2009), No.7, pp. 174-181.
5. H. Sun, Y.C. Liu and M.J. Lu: "Kinetics of Magnesium Vapor Bubble in Hot Metal," Progress Report 12, R & D Department, China Steel, August 2009.
6. H. Sun, Y.C. Liu and M.J. Lu: "Desulfurization of Hot Metal Bath by Magnesium Addition" Progress Report 16, R & D Department, China Steel, April 2010.
7. H. Sun, Y.C. Liu and M.J. Lu: Ironmaking & Steelmaking, 2010, 37, (8), pp. 599-606.
8. Y.C. Liu, H. Sun and M.J. Lu: Bulletin of Chinese Institute of Mining and Metallurgy Engineers, 2010, 54, (4), pp. 51-60.
9. Private communication: K.L. Hwang: "Simulation of Velocity Field in the Hot Metal in a Ladle by Gas Injection", R & D Department, China Steel, September 2008.
10. H. Sun, Y.C. Liu and M.J. Lu: "Process Simulation of Hot Metal Desulphurization by Magnesium Injection," 4th International Conference on Process Development in Iron and Steel-making (SCANMET IV) , 10-13 June 2012, Luleå, Sweden, Paper No. 2012-033, (2012).
11. Japan Society for Promotion of Science and Technology, 19th Committee of Steel Making: Recommended Equilibrium Value of Steel-Making, Tokyo, Nov., (1984), p. 225.
12. Q. Han D. Zhou and C. Xiang: Steel Research, 68 (1988), p. 9.
13. E. T. Turkdogan: Fundamentals of Steelmaking, 19 (1992), p.136.
14. H.J. Visser and R. Boom: ISIJ International, 46 (2006), No. 12, pp. 1771-1777.
15. Y. Hiraga, K. Gennai, H. Nagashima and J. Hiram: CAMP-ISIJ, 9 (1996), p. 225. □