Slag—Metal Relations in Metalloys' High-carbon Ferromanganese Furnaces

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SYNOPSIS

High-carbon ferromanganese is produced by Amcor's Metalloys plant near Meyerton in the Transvaal. Closed electric furnaces of the order of 9 to 11 MW are used. A description of furnace parameters is given.

Local raw materials only are used. Manganese ores come from the Hotazel and Mamatwan Mines, and the reducing agent is coal from Delmas Colliery. Metalloys is thought to be the only place where coal only is used as a reducing agent A description of raw materials, raw-materials and heat balances, the smelting characteristics, and results are given.

During a period of half a year, metal and slag analyses have been carried out at each tap. Because of railway transport from the mines and poor blending facilities at the works, constant operation is impossible, and slag and metal analyses vary to such an extent that the metal has to be sorted according to each tap analysis. A correlation between slag and metal analysis has been sought. At constant silicon content of the alloy, there seems to be a direct correlation between the manganese oxide content and the ratio of lime to silica. Variations in the magnesia and alumina do not appear to interfere materially with this correlation. Graphs showing this correlation for varying silicon contents of the alloy are given.

INTRODUCTION

High-carbon ferromanganese was produced during the first half of 1973 in four furnaces at the Metalloys plant near Meyerton in the Transvaal, South Africa. After an X-ray spectrophotometer had been installed, more-complete metal and slag analyses from each tap were obtainable. Two new 48 MVA furnaces commenced operation during the second half of 1973. This new arrangement also includes a crushing and screening plant and an automatic sampling device installed between the screening plant and the weighing silos. For operation of the new furnaces, the mixture is based mainly upon the raw-material analyses. In our case, where the raw material arrives in small quantities by rail instead of in shiploads, as is the practice overseas, the raw materials vary considerably more, and control over their smelting is more difficult. This analysis of corresponding metal and slag compositions is an attempt to find the best solution for controlling the metal and slag analyses.

THE FURNACES

The four furnaces mentioned are Nos. 1, 2, 3, and 7. The first three of those are closed, and No. 7 is open. All were constructed by African Metals Corporation Limited (now Amcor). Their dimensions and other pertinent information are given in Table 1. It must be mentioned that the gas-cleaning system was designed for the use of coke as a reducing agent. With coal only as a reducing agent, the excessive gas formed cannot be taken by the gas system, and there is therefore some smoke escaping from the furnace roof.

RAW MATERIALS

Only local raw materials are used. The manganese ores are from the Mamatwan and Hotazel Mines, and the coal used as a reducing agent comes from the Delmas Colliery, in the Transvaal. Typical analyses of the raw materials are given in Tables 2 to 4. Mamatwan ore consists mainly of braunite, manganite, ankeritic dolomite, and smaller amounts of hausmanite and calcite. There are traces of pyrolusite. The behaviour of this ore when heated in air and hydrogen is shown in Figures 1 and 2. The main manganese orebodies in the Mafeking—Kuruman area in the Cape are of the Mamatwan type. It is believed that the Mamatwan type of ore was changed to the Hotazel type in places where a secondary heating had taken place, followed by exposure to rain containing carbon dioxide millions of years ago. The calcined dolomite and limestone were washed away, and the braunite was partly changed to hausmanite. Common to both ores is a very low phosphorus content and an unusually low alumina content.

In the future, ore from the Wessels Mine will also be used. To the present, however, we have had very little experience with this ore.

Table 1

Dimensions of high-carbon ferromanganese furnaces at Metalloys
(All these furnaces are of the fixed-shell type and the electrode arrangement is triangular.)

No.	Supply kV	Transformer power MVA	Shell diam. m	Shell height m	Electrode type	Electrode diam. mm	Electrode pitch-circle diam. mm	Furnace type
1	11	10	8,34	4,25	3 Self baking	1090	3100	Closed
2	11	13,2	9,52	3,40	3 Self baking	1270	3810	Closed
3	11	13,2	9,52	3,40	3 Self baking	1270	3810	Closed
7	11	10	7,09	4,25	3 Self baking	890	2590	Open

*Amcor Management Services (Pty) Limited, South Africa.

Table 2

Ore analyses and calculated mineralogical composition

Components	Hotazel	Mamatwan	Components	Hotazel	Mamatwan
MnO_2	35,00	34,20	(Mn)	55,00	38,40
MnO	42,50	21,70	(Fe)	9,26	4,22
Fe_2O_3	13,20	6,03	(Mn)/(Fe)	5,95	9,1
CaO	1,75	10,50	Braunite	44,2	47,6
MgO	0,31	4,10	($3\ Mn_2O_3 \cdot MnSiO_2$)		
BaO	Trace	Trace	Hausmanite	38,9	5,0
Al_2O_3	0,48	0,45	(Mn_3O_4)		
SiO_2	4,39	4,73	Manganite	12,2	15,7
TiO_2	Not determined	Not determined	($MnO \cdot OH$)		
CO_2	0,65	13,70	Hollandite	Trace	Trace
Comb.H_2O	1,25	1,61	($BaMn_8O_{16}$)		
Na_2O	0,18	0,39	Dolomite	1,42	18,8
K_2O	0,13	0,53	($CaMg \cdot 2CO_3$)		
P	0,037	0,026	Calcite	2,35	8,6
S	Not determined	Not determined	($CaCO_3$)		

Table 3

Analyses of Delmas pea coal and coal ash

	Calorific value	H_2O	Ash	Volatile matter	Fixed carbon	Total sulphur	Ash fusion temp.
Coal analysis	27,0 MJ/kg	4,3%	12,7%	28,0%	55,0%	0,7%	1370°C
Ash analysis	SiO_2 42,8%	CaO 10,9%	MgO 2,92%	Al_2O_3 27,4%	TiO_2 1,20%	Mn 0,44%	P 0,13%

Table 4

Example of size distribution of raw materials as received

Size, inches	>3 %	>2 %	>1½ %	>1 %	>¾ %	>½ %	>¼ %	<¼ %	>⅛	<⅛
Mamatwan	0,2	2,7	7,4	36,4	55,3	77,9	92,8	7,2		
Hotazel	5,3	22,6	34,2	48,4	56,0	71,5	85,7	14,3		
Quartz	1,6	21,1	45,2	67,5	76,8	83,6	88,9	11,1		
Delmas coal					6,1	47,4	81,4		88,3	11,7

The coal from Delmas Colliery is from the No. 2 seam, and is actually the same type as is used for the thermal power stations in the Witbank area. The coal has no swelling properties, a fact that is essential for calm furnace operation. The low smelting point (1370°C) of the ash is most probably the reason for a high reactivity.

Occasionally fluxes such as quartz and dolomite are used.

OPERATION

The raw materials are stored in heaps according to grade. Special care is taken with the Hotazel ore, owing to tremendous variation in analysis, and it is split into heaps according to its manganese-to-iron ratio. The only material screened is the Delmas coal, which passes over a Mogensen sizer where the minus 3mm material is removed (and sold to the nearest power station).

Continuous weighing is used, but unfortunately it is not of high accuracy.

The furnaces are charged round the electrodes. The system is shown in Figure 3.

The furnaces are tapped every 3 hours, and a number of spoon-samples are taken of both metal and slag.

Either a high-grade slag with an MnO content of about 40 per cent is made (the enriched slag process in the production of 70 to 75 per cent Mn metal), or a low-grade slag is made (the throwaway-slag process in the production of 75 to 80 per cent Mn metal). The 40 per cent MnO slag is re-used for the production of silicomanganese. Smelting balances in both operations are shown in Tables 5 and 6, and a heat balance in Table 7.

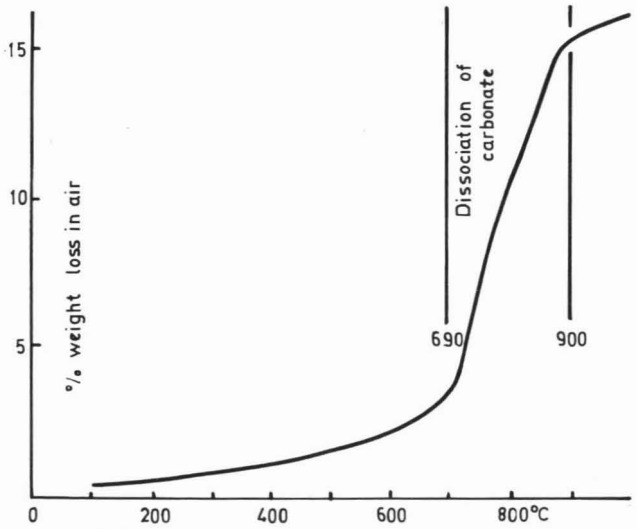

Figure 1
The behaviour of Mamatwan ore when heated in air

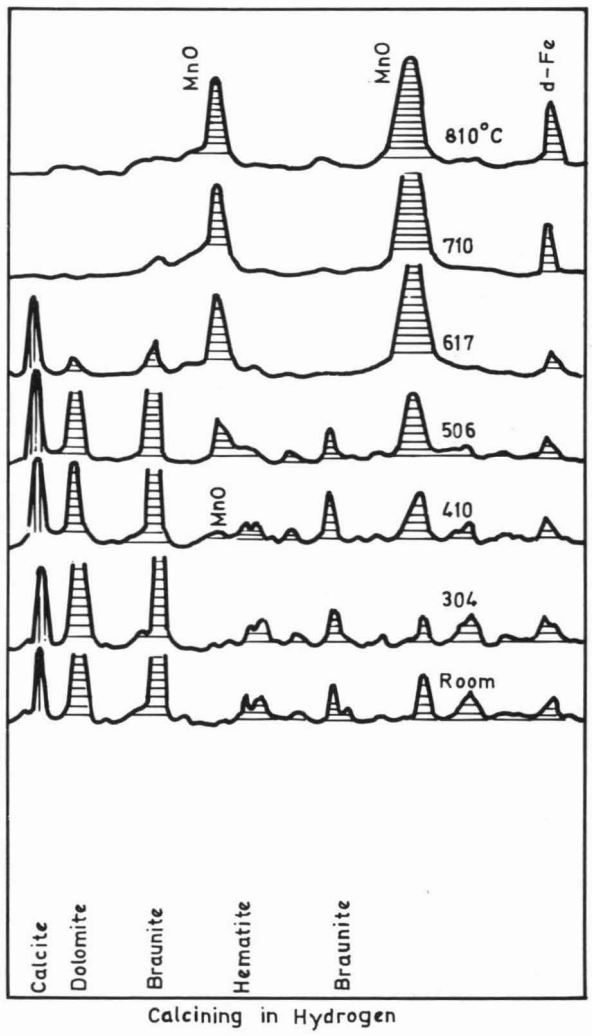

Figure 2
The behaviour of Mamatwan ore when heated in hydrogen

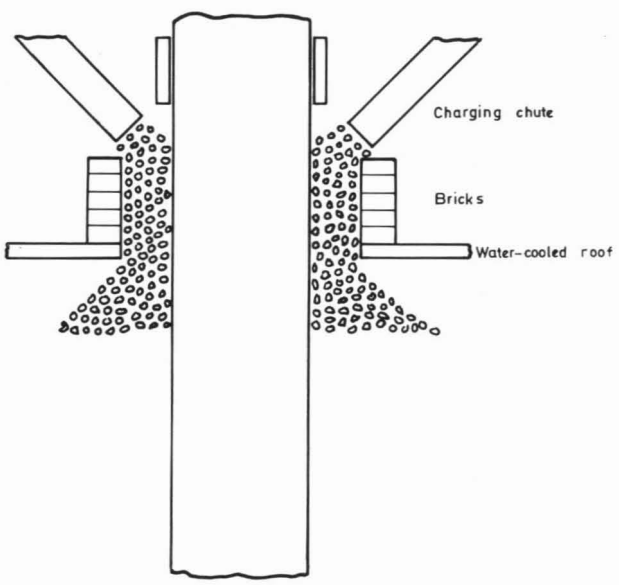

Figure 3
Charging arrangement for furnaces Nos. 1, 2, and 3

Table 5
Material balance for the enriched-slag process

				Slag components						Metal components				
Materials	%	MnO	FeO	CaO	MgO	Al_2O_3	SiO_2	$Na_2O + K_2O$	TiO_2	Mn	Fe	Si	C	P
Hotazel	85			1,48	0,26	0,41	3,73	0,26	—	46,75	7,87			0,0314
Mamatwan	15			1,57	0,61	0,07	0,71	0,14		5,76	0,63			0,0039
Delmas coal	36			0,50	0,13	1,25	1,96		0,05	0,02				0,0059
Total				3,55	1,00	1,73	6,40	0,40	0,05	52,53	8,50			0,0412
To metal							0,10					0,05		
To slag		8,12	0,01							6,29				
Smoke losses				0,08	0,07	0,21	0,59			2,62	0,21			
Final total to slag and metal		8,12	0,01	3,47	0,93	1,52	5,71	0,40	0,05	43,62	8,29	0,05		
Analyses, %		40,0	0,07	17,1	4,58	7,48	28,1	1,97	0,25	77,34	14,70	0,09	6,80	0,07
Mass of slag and metal									20,3					56,4

Table 6

Material balance for the throwaway-slag process

		Slag components								Metal components				
Materials	%	MnO	FeO	CaO	MgO	Al_2O_3	SiO_2	$Na_2O + K_2O$	TiO_2	Mn	Fe	Si	C	P
Hotazel	50			0,87	0,15	0,24	2,20	0,15		27,50	4,63			0,0185
Mamatwan	50			5,25	2,05	0,23	2,36	0,41		19,20	2,11			0,0130
Delmas coal	34			0,47	0,12	1,85	1,18		0,05	0,02				0,0056
Total				6,59	2,32	1,65	6,41	0,56	0,05	46,72	6,74			0,0371
To metal							0,10					0,05		
To slag		3,17								2,45				
Smoke losses				0,07	0,06	0,18	0,52			2,34	0,18			
Final total to slag and metal		3,17		6,52	2,16	1,47	5,79	0,56	0,05	41,93	6,56	0,05	3,58	0,0371
Analyses, %		16,0	0,07	32,9	10,9	7,42	29,2	2,83	0,25	79,56	12,44	0,10	6,8	0,07
Mass of slag and metal									19,8					52,7

Owing to variations in the ores, and also inaccurate weighing, analyses of the slag and metal vary considerably, which naturally upsets the furnace operation. We have collected corresponding analyses of slag and metal, sorted according to their manganese and silicon contents.

Large variations in the iron content of the slag are due to entrapped metal. Provision has been made for this. On Figure 4 is shown a number of slags with FeO contents from 0,07 to 0,16 per cent. A content of 0,07 per cent appears to be the lower limit. It is not impossible that slags recorded with higher FeO values actually have an FeO content of only 0,07 per cent, the remainder being finely dispersed metal. The slag analyses have therefore been corrected for the metallic content.

RESULTS

The following formulae were used in an attempt to find the relations between the slag components:

(1) $$\frac{\%(CaO)}{\%(SiO_2)}$$ L. Blum, 1901

(2) $$\frac{\%(CaO)+\%(MgO)}{\%(SiO_2)}$$

(3) $$\frac{\%(CaO)+\%(MgO)}{\%(SiO_2)+0{,}6\%(Al_2O_3)\left[\frac{\%(CaO)+\%(MgO)}{\%(SiO_2)}-1{,}19\right]}$$

Chou Yuan-Hsi, 1956

(4) $$\frac{\%(CaO)+0{,}7\%(MgO)}{0{,}94\%(SiO_2)+0{,}18\%(Al_2O_3)}$$

M. R. Kalyanram, T. A. McFarlane, and H. Bell, 1960

(5) $$\frac{\%(CaO)+\alpha\%(MgO)+2{,}0\%(MnO)}{\%(SiO_2)+0{,}6\%(Al_2O_3)\left[\frac{\%(CaO)+\alpha\%(MgO)}{\%(SiO_2)}-1{,}19\right]}$$

Table 7

Heat balance

(Base 1000 g of ores)

Mixture: Hotazel 70, Mamatwan 30, Delmas coal 29.
Complete mixture, in moles:

Mn_2O_3	0,627	$CaCO_3$	0,995
$MnSiO_3$	0,173	$MgCO_3$	0,404
Mn_3O_4	1,075	SiO_2	0,330
Fe_3O_4	0,479	Comb.H_2O	1,067
Al_2O_3	0,202	C	14,220

Heat required to heat the mixture to 700°C and drive off combined H_20 = + 155 449 cal.

Reactions that take place in the solid state at approximately 700°C:

Calcination of $CaCO_3$ and $MgCO_3$.

Reduction of higher oxides to lowest oxides by CO.

$CaCO_3 = CaO + CO_2$	+40 237 cal
$MgCO_3 = MgO + CO_2$	+8 717 cal
$Mn_2O_3 + CO = 2MnO + CO_2$	− 14 381 cal
$Mn_3O_4 + CO = 3MnO + CO_2$	− 13 746 cal
$Fe_3O_4 + CO = 3FeO + CO_2$	+1 863 cal
Total:	+ 22 690 cal

Heat required for driving off the volatiles from Delmas coal	+ 101 500 cal
Heat required for heating the mixture from 700 to 1400°C	+ 135 000 cal
Heat of fusion at 1400°C	+ 104 600 cal

Reactions at 1400°C:

$MnO + 4C = Mn_3C + CO$	+609 265 cal
$FeO + 4C = Fe_3C + CO$	+39 564 cal
$SiO_2 + 2C = Si + 2CO$	+2 822 cal
Total:	+ 651 651 cal

Heat liberated by CO from 1400 to 700°C	− 48 640 cal
Heat liberated by CO and CO_2 from 700 to 250°C	− 45 000 cal

where $\alpha = \dfrac{1{,}84\,\%(SiO_2) - 0{,}9\,\%(CaO)}{\%(SiO_2) + 0{,}9\,\%(MgO)}$

I. S. Kulikov, 1962

(6) $$\frac{(CaO)}{(SiO_2)}$$

(7) $$\frac{(CaO)+(MgO)}{(SiO_2)}$$

(8) $$(CaO)+\tfrac{2}{3}(MgO)-(SiO_2)-(Al_2O_3)$$

G. G. Hatch and J. Chipman, 1949

Fifty-two slags from No. 1 furnace with MnO contents varying from 38 to 50 per cent, MgO from 4 to 5 per cent, and Al_2O_3 nearly constant, and these slags from taps where the corresponding metal had contents of Mn from 70 to 75 per cent, Si from 0,04 to 0,06 per cent, and C from 6,8 to 6,9 per cent, gave the results listed in Table 8.

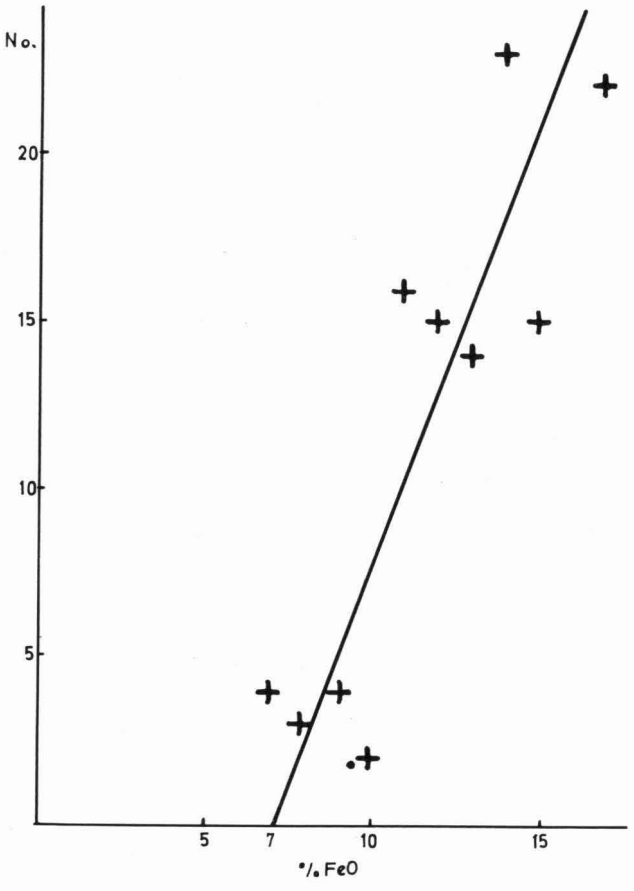

Figure 4

Analyses of charges containing various amounts of FeO

Table 8

Results of investigation of slag relations

No.	Closest curve* $y=$	Max. % difference between actual and calculated value for x	
(1)	$-0{,}0206x+1{,}4067$	+14,8	−19,2
(2)	$-0{,}0219x+1{,}641$	+12,2	−14,8
(3)	$-0{,}0169x+1{,}359$	+13,0	−14,6
(4)	$-0{,}0212x+1{,}554$	+13,8	−16,9
(5)	$0{,}0828x-0{,}057$	+ 3,6	− 5,9
(6)	$-2{,}2685x+1{,}457$	+13,2	−18,6
(7)	$-2{,}5153x+1{,}804$	+10,4	−15,4
(8)	$-0{,}6209x+0{,}107$	+21,8	−26,8

*y = (1) to (8) as listed earlier
x = %(MnO) and (MnO)

The best curve appears to be

$$\%(MnO) = 0{,}0828\ (5) - 0{,}057$$

with a maximum percentage difference of +3,6 and −5,9 in the actual values from the curve, which are close to the expected analytical error for MnO.

To get an idea of to what extent CaO could be replaced by MgO, the ratio

$$\frac{\%(CaO)+\%(MgO)}{\%(SiO_2)}$$

was plotted against %(MnO) for slags with contents of 4 to 5 per cent (MgO) and 5 to 6 per cent (MgO)– Figure 5. It will be noticed that the two lines are far apart. These figures are for high-MnO slags.

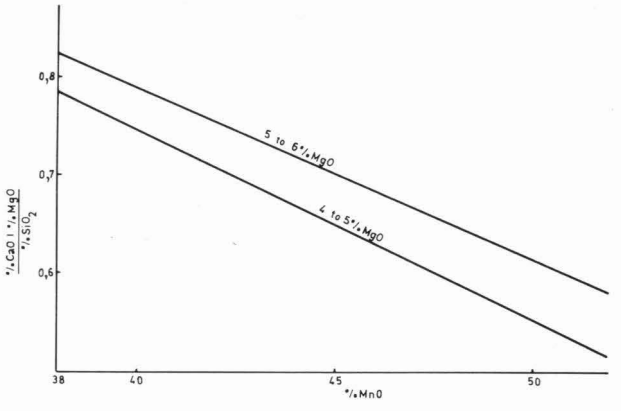

Figure 5

Percentage of MnO in the slag as a function of the basicity formula $\dfrac{\%\ CaO\ +\ \%\ MgO}{\%\ SiO_2}$ *for various percentages of MgO in the slag*

For slags in the range 16 to 30 per cent (MnO), the ratio

$$\frac{\%(CaO)}{\%(SiO_2)}$$

was plotted against %(MnO) in the slag for slags with contents of 6 to 7 per cent (MgO) and 7 to 8 per cent (MgO).

This was done for slags from Si analyses of 0,05, 0,10, and 0,15 per cent. It must be noted that, in all cases, the lines crossed each other (Figures 6 to 8).

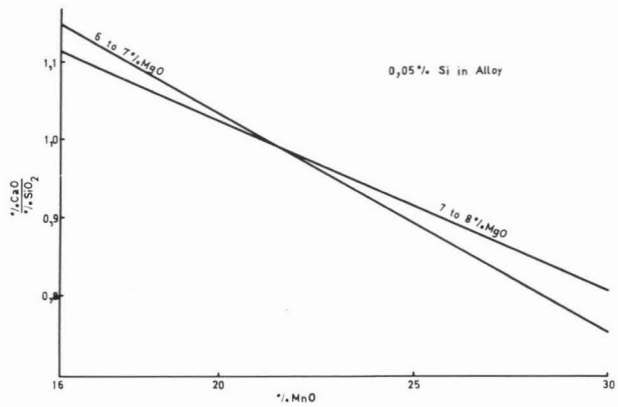

Figure 6

Percentage of MnO in the slag as a function of the basicity formula $\frac{\%\ CaO}{\%\ SiO_2}$ *for constant Si content of the alloy*

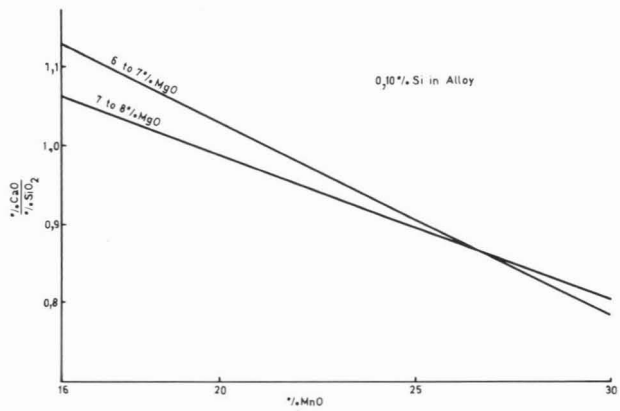

Figure 7

Percentage of MnO in the slag as a function of the basicity formula $\frac{\%\ CaO\ +\ \%\ MgO}{\%\ SiO_2}$ *for various percentages of MgO in the slag*

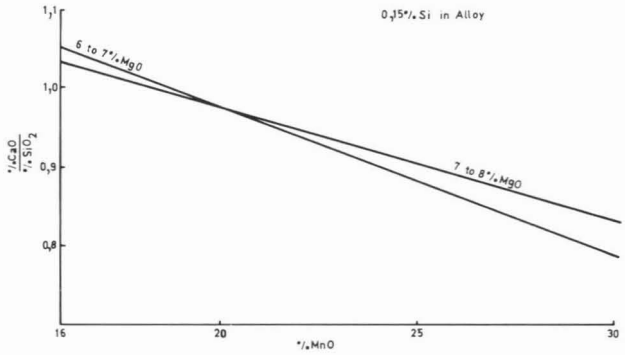

Figure 8

Percentage of MnO in the slag as a function of the basicity formula $\frac{\%\ CaO}{\%\ Sio_2}$ *for constant Si content of the alloy*

DISCUSSION

FeO Content of the Slag

For the reaction

(FeO) + [Mn] = (MnO) + [Fe], where ( ) refers to slag and [ ] to metal, $\Delta\ 1673 = -14900$ cal,

which corresponds to

$$K = 88{,}5.$$

Taking a slag consisting of

MnO	CaO	MgO	Al_2O_3	SiO_2
15	40,4	8,9	10	25,7

the ^{a}(MnO) = 0,2[1].

Taking ^{a}[Fe] and ^{a}[Mn] equal mole fractions in the metal, then, since

$$K = \frac{^a[Fe] \times {}^a(MnO)}{^a[Mn] \times {}^a(FeO)}$$

$$^a(FeO) = 0{,}00056.$$

Assuming ^{a}(FeO) in this type of slag to correspond, more or less, to ^{a}(MnO), and also forming a straight line from zero,

$$\%FeO = 15 \times \frac{0{,}00056}{0{,}20} = 0{,}04.$$

The assumption of 0,07 per cent FeO in the slag and anything reported higher than this to be metal inclusions does not therefore appear unrealistic.

Accuracy of Curves

Except for the extreme differences between actual and calculated values for (MnO) when basicity formula (8) was used and the good agreement when formula (5) was used, the other basicity formulae gave more or less the same inaccuracy.

The reason for the high accuracy when formula (5) was used is most probably that the %(MnO) in the slag, in addition to being a function of %(CaO), %(MgO), $\%(SiO_2)$, and $\%(Al_2O_3)$, also is a function of 2 × %(MnO), and the effect of the last one overshadows the others.

The effect of MgO in the (5) formula has been reduced by a factor

$$\alpha = \frac{1{,}84 \times \%(SiO_2) - 0{,}9 \times \%(CaO)}{\%(SiO_2) + 0{,}9 \times \%(MgO)}$$

For the following two slag analyses, the α values are 1,25 and 0,73:

	MnO	FeO	CaO	MgO	Al_2O_3	SiO_2
(1)	46,0	0,07	13,0	4,52	8,04	28,4
(2)	18,5	0,07	34,3	7,89	6,65	32,6

On inspection of the graphs for (2) for %(MgO) varying from 4 to 5 and 5 to 6 (in contact with metal of the same silicon specification), the value for α can be calculated by use of the points A and B from Figure 5:

$$\frac{\%(CaO) + \alpha\%(MgO)}{\%(SiO_2)} = \text{constant}$$

$$\alpha = -0{,}1.$$

If the free energy of formation of metasilicates at 1500°K is taken as

Mn SiO_3 1,4 kcal/mol,
Mg SiO_3 7,3 kcal/mol,
Ca SiO_3 21,1 kcal/mol,

it is likely that the CaO forms the strongest combination with SiO_2.

It can be assumed that the high percentage of MnO, combined with an increasing activity of MnO as the percentage increases[1], results in more SiO_2 being combined with MnO than with MgO, and that MgO for MnO-rich slags can be left out as part of a basicity formula.

In Figures 6 to 8, it can be seen that the lines for %(MnO) as functions of $\%(CaO)/\%(SiO_2)$ for varying contents of MgO cross each other. This is an indication that only below a certain percentage of MnO in the slag does MgO really start to take effect as a basic slag component.

With MgO playing such an unimportant part on a basicity formula within the practical range of slags, it is unlikely that Al_2O_3 could have much effect either.

For all practical purposes, we are back to one of the original basicity formulae, namely

$$\frac{\%(CaO)}{\%(SiO_2)}.$$

For a slag corresponding to metal of 70 to 80 per cent Mn and 0,05 per cent Si, the formula

$$\frac{\%(CaO)}{\%(SiO_2)} = f(\%MnO)$$

becomes simply

$$\frac{\%(CaO)}{\%(SiO_2)} = -0{,}0214 \times \%(MnO) + 1{,}4416,$$

which is valid in the range of 15 to 45 percent (MnO).

For higher percentages of silicon in the alloys, the equations are as follows:

$$0{,}10\%\ Si: \frac{\%(CaO)}{\%(SiO_2)} = -0{,}0208 \times \%(MnO) + 1{,}4126$$

$$0{,}20\%\ Si: \frac{\%(CaO)}{\%(SiO_2)} = -0{,}0197 \times \%(MnO) + 1{,}3543$$

$$0{,}30\%\ Si: \frac{\%(CaO)}{\%(SiO_2)} = -0{,}0186 \times \%(MnO) + 1{,}2958.$$

The free oxygen can be calculated according to the following reactions, as suggested by Healy[3], based on the fact that oxides dissolve in a basic slag as ions:

Basic oxides: $CaO = Ca^{2+} + O^{2-}$
$MgO = Mg^{2+} + O^{2-}$
$MnO = Mn^{2+} + O^{2-}$
$FeO = Fe^{2+} + O^{2-}$

Acid oxides: $SiO_3 + 2\,O^2 = SiO_4^4$
$Al_2O_3 + 3\,O^2 = 2AlO_3^3$

From Table 9 it can be seen that there is insufficient oxygen available from the cations for all the SiO_2 and Al_2O_3 to form SiO_4^{4-} and AlO_3^{3-} anions. With the slag in contact with metal having a silicon content of 0,05 per cent, the slag could not be characterized as acid.

Table 9

Slag analysis by mass %		Molecular mass	mol/100g	Ions formed	Oxygen supplied or consumed
CaO	33,5	56	0,598	0,598 Ca^{2+}	0,598
MgO	7,89	40	0,197	0,197 Mg^{2+}	0,197
MnO	18,5	71	0,261	0,261 Mn^{2+}	0,261
FeO	0,07	72	0,001	0,001 Fe^{2+}	0,001
Total oxygen supplied: 1,057					
SiO	31,9	60	0,532	0,532 SiO_4^{4-}	1,064
Al_2O_3	6,65	102	0,065	0,130 Al_3^{3-}	0,195

Total oxygen consumed: 1,259
Total free oxygen: 1,057 – 1,259 = –0,202 (or zero)

For all values of MnO plotted against

$$\frac{\%(CaO)}{\%(SiO_2)}$$

according to the simple equation

$$y = ax + b,$$

and, being in contact with metal of constant manganese and silicon values, the $^a(MnO)$ or $^a(O^{2-})$ must be constant. If not, the reaction

$$2MnO + Si = Mn + SiO_2$$

would take place.

A slag with the following content will have an $^a(MnO)$ or $^a(O^{2-})$ of 0,14, and the corresponding pO value of

$$pO \equiv -\log {}^aO^{2-} \equiv 0{,}85:$$

MnO	CaO	MgO	Al_2O_3	SiO_2
18,5	34,3	7,9	6,6	32,6

Using the formula of Frohberg and Kapoor[5] for the metal oxide activity or the pO value is at this stage impossible because there is not sufficient SiO_2 in the slag for the formation of metasilicates, for which only the K and α values were published.

CONCLUSION

At this stage it appears that the most practical basicity formula for the plant operators to work with is still the old-fashioned $\%(CaO)/\%(SiO_2)$, and the equation for calculating the corresponding $\%(MnO)$ is of the simple form:

$$\%(MnO) = \frac{\%(CaO)}{\%(SiO_2)} \times a + b,$$

where a and b depend upon which percentage silicon in the alloy is wanted.

REFERENCES

1. WARREN, G.F. Measurement of the activity of manganese (II) oxide in slags associated with the production of ferromanganese. M.Sc. Thesis. Johannesburg, University of the Witwatersrand, 1972.
2. PENTZ, R.D. 'n Ondersoek na die veredeling van laegraadse mangaanerts met besondere verwysing na die reduseerbaarheid. M.Sc. Thesis, Potchefstroom. Potchefstroom Universiteit vir Christelike Hoër Onderwys, 1970.
3. HEALY, G.W. A new look at phosphorus distribution. *J. Iron Steel Inst.* vol. 208. 1970. pp. 664-668.
4. FROHBERG, M.G. Die Anwendung der Ionentheorie auf Metallurgische Schlacken unter besonderer Berücksichtigung der Sauerstoff- und Schwefelverteilung. *Arch. Eisenhüttwes.*, vol. 9, 1961. pp. 597-606.
5. FROHBERG, M.G., and KAPOOR, Lal. Die Anwendung eines neuen Basizitätsmasses auf metallurgische Reaktionen. *Stahl Eisen*, vol. 91, no. 4. 1971. pp. 182-188.

In the delivery of his paper, **Mr Selmer-Olsen** mentioned that Metalloys did not blend their raw materials. This resulted in fluctuations in the composition of the feed to the ferromanganese furnaces, with consequent problems. After his presentation, he turned the tables on his audience and asked THEM to answer two questions. The first question was whether any one in the audience had also found that, in high-MnO slags, the MgO content of the slag had an insignificant effect on the basicity. Then, in discard-slag practice, when the MgO is increased from 5 to 10 per cent, the metal and slag get hotter and hotter. This probably had nothing to do with the coke bed in the furnace. He asked the audience whether they had had the same experience and asked them to explain this phenomenon. No ready answers were forthcoming. Eventually Mr Sciarone (Metalloys Ltd, South Africa) ventured to suggest that in discard-slag practice the MgO content is high. Because of the manner of calculating the basicity, higher basicity values are obtained as the MnO is replacing MgO and CaO. These slags would also have higher liquidus temperatures.