The Production of Ferrosilicon—Chromium by the Single-stage Process

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SYNOPSIS

A plant is described for the production of ferrosilicon—chromium alloy, comprising two 17,5 MVA submerged-arc furnaces. The single-stage process is operated with raw materials, chromium ore, quartz, and coke.
Operating data and production results are given and metallurgical balances presented. A comparison is also made between actual results and basic thermodynamic calculations with regard to the effect of a number of operating variables.

INTRODUCTION

Ferrosilicon—chromium alloy is produced at Rhodesian Alloys Limited for two purposes: (1) as an intermediate product for the manufacture of low-carbon ferrochromium alloy by the Perrin process, and (2) as alloy for direct sale, for use in stainless-steel production.

The advantages of the use of ferrosilicon—chromium alloy in stainless-steel melting are particularly at the deoxidizing stage: a low-carbon alloy (0,05 per cent carbon maximum) can be used at lower cost than ferrosilicon, and low-carbon ferrochromium alloys are added as separate constituents.

The principal units used to produce ferros licon —chromium for sale at Rhodesian Alloys are two 17,5 MVA submerged-arc furnaces. The single-stage process is used; chromium ore, quartz, and coke, together with recycled revert material, are charged to the furnace, and ferrosilicon—chromium alloy and slag are tapped.

A number of alloy specifications are made to meet particular customer requirements, chiefly varying in the chromium content, for example, Cr 36 to 38 per cent and > 39 per cent; silicon content specified is normally in the range 40 to 46 per cent. While Rhodesian Alloys are willing to meet any reasonable alloy specification, encouragement is given to standardizing on composition, which facilitates stocking and distribution.

PLANT

Both the submerged-arc furnaces are of the same design, and a brief technical description is given in Table 1.

Figure 1 shows an outline plan and sectional elevation of the furnaces.

Table 1

Technical description of submerged-arc furnaces

Type of furnace	Open rotating
Transformer	
Rating	17 500 MVA
Primary voltage	33 kV, 50 Hz
Secondary voltage	95 to 187V 25 tap positions
Secondary current	63 kA maximum
Furnace equipment	
Electrode type	Self-baking
Electrode diameter	1 100 mm
Electrode pitch-circle diameter	2 550 to 3 050 mm
Furnace shell: diameter	7 500 mm
height	4 500 mm
Hearth: diameter	4 600 mm
inside height	2 697 mm
Vertical electrode movement	1 016 mm

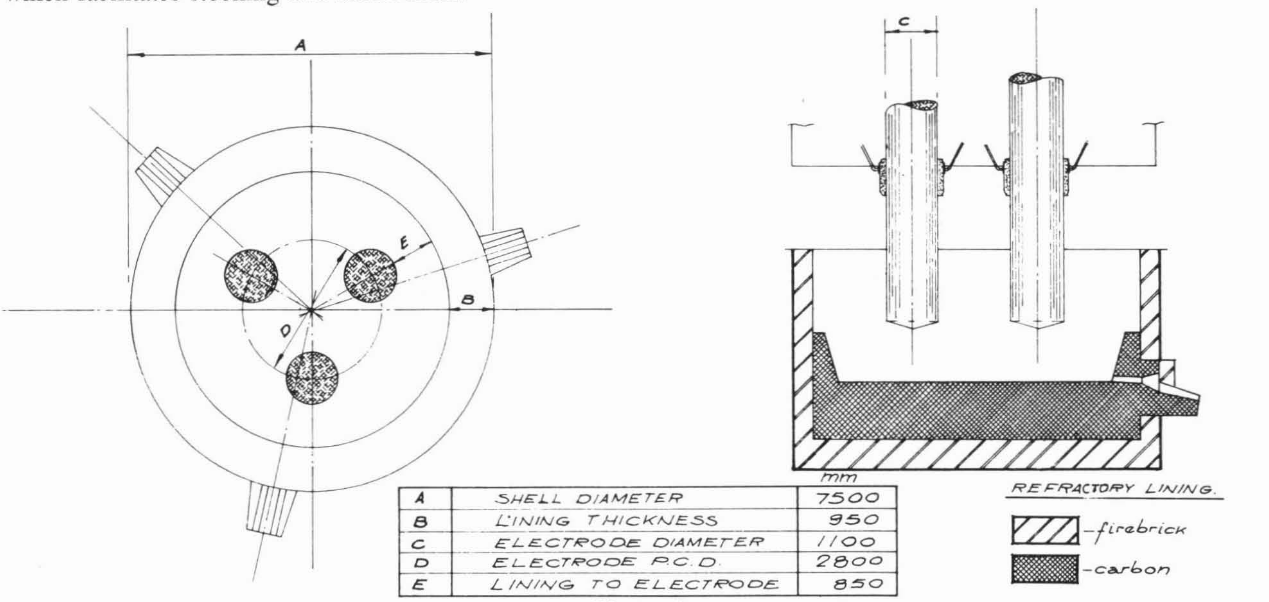

Figure 1

Outline plan and sectional elevation of 17,5 MVA furnaces

*Rhodesian Alloys Limited, Rhodesia.

Table 6

Data on raw materials and consumables

Period	May, 1972		May, 1973	
	A2 Furnace		Al Furnace	
	Tonnes	per tonne of alloy	Tonnes	per tonne of alloy
Raw materials				
Chromium ore: A	980	0,619	—	—
B	980	0,619	1266	0,799
C	—	—	847	0,534
Coke	1168	0,737	1181	0,745
Quartz	2097	1,323	2036	1,285
Steel scrap	38	0,023	—	—
Jig concentrate	42,2	0,027	—	—
Consumables				
Electrode casing	5,2	0,003	4,5	0,003
Steel bar	14,6	0,009	20,3	0,013
Paste: Electrodes	73,9	0,047	67,3	0,042
Tapholes	4,2	0,003	1,2	0,001
Gumpoles (each)	1487	0,94	776	0,49

Table 7

Chemical analyses and chromium recovery

Period	May, 1972 A2 Furnace	May, 1973 A1 Furnace
	%	%
Chemical analyses		
Alloy: Cr	38,60	39,40
Si	43,50	42,84
Slag: Cr_2O_3	0,9	0,5
FeO	0,8	0,3
SiO_2	48,5	49,9
Al_2O_3	21,6	20,6
MgO	24,6	25,9
CaO	2,9	2,9
C	1,39	1,92
Ratio MgO/Al_2O_3	1,14	1,25
Revert material		
New — Jig concentrate Cr	36,9	—
Recycled — Ladle/dump return Cr	14,4	8,7
Chromium recovery	92,8	90,4

No significant effect can be attributed to an MgO/Al_2O_3 ratio between 1,1 and 1,3. The carbon content of the slag is recorded, as an indication of silicon carbide formation, and is normally between 1,0 and 2,0 per cent.

The chromium recovery from raw materials into ferrosilicon—chromium alloy for sale is typically in the range 90 to 93 per cent.

COMPARATIVE THERMODYNAMIC CALCULATIONS

It is possible to calculate the energy required to produce chromium, silicon, and iron from their oxides, and superheat to furnace temperature, as well as the heats of formation of the slag constituents.

Thermodynamic calculations have been carried out to determine the energy used to produce ferrosilicon—chromium alloy and slag. To these data has been added appropriate information on the electrical losses from the furnace transformer and secondary circuits, calculated heat losses from the furnace, and the additional energy required for loss of silicon by evaporation. The total energy for the ferrosilicon — chromium process is related to production on the basis of a 15 MW furnace input at 95 per cent availability.

Full details of these calculations are not presented in this paper, but the value of the work has been to obtain the quantitative expected effect of a number of operating variables, and four examples are given. In these examples, standard conditions postulated for 1 tonne of alloy produced are chromium and silicon contents of 40 per cent and 42 per cent, respectively, in the alloy, 0,79 tonnes of slag, silicon stack loss of 3 per cent, alloy loss of 5 per cent, and recirculation of 3 tonnes of tundish and 7 tonnes of ladle revert per day.

In Figure 2, the separate effects of varying the chromium and silicon contents in the alloy are considered. It will be seen that, whereas chromium has no large effect, an increasing silicon content requires significantly more power, and consequently this would be expected to lower the production rate accordingly.

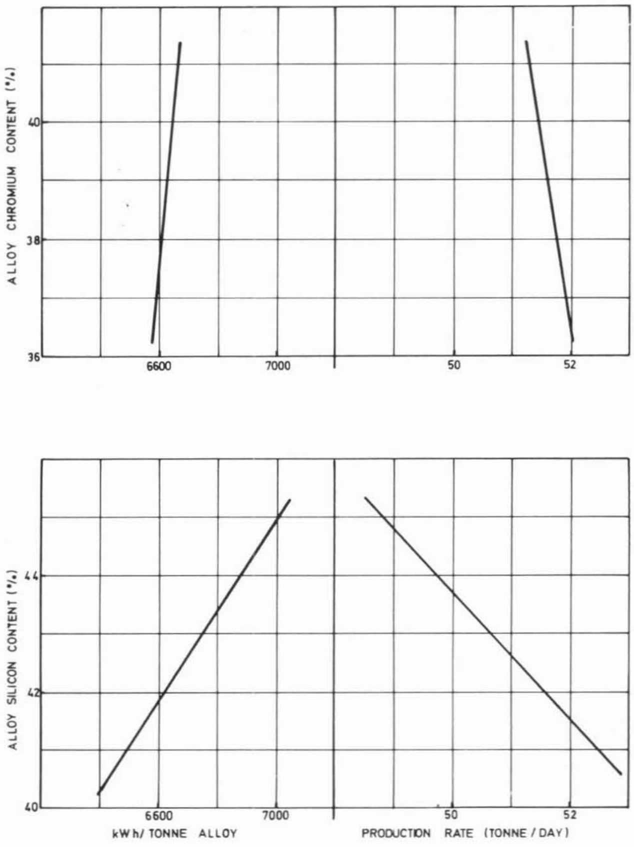

Figure 2

Relation of the chromium and silicon contents of the alloy to the production rate of ferrosilicon–chromium and to the power consumption

Figure 3 illustrates the importance of minimizing the alloy losses by entrainment in the slag, and silicon losses by evaporation from the furnace.

Usually it is not easy to separate the effect of different operating variables from production data, because these variables can be interrelated and practical conditions can vary. However, these quantitative calculations have proved useful in interpreting the furnace condition.

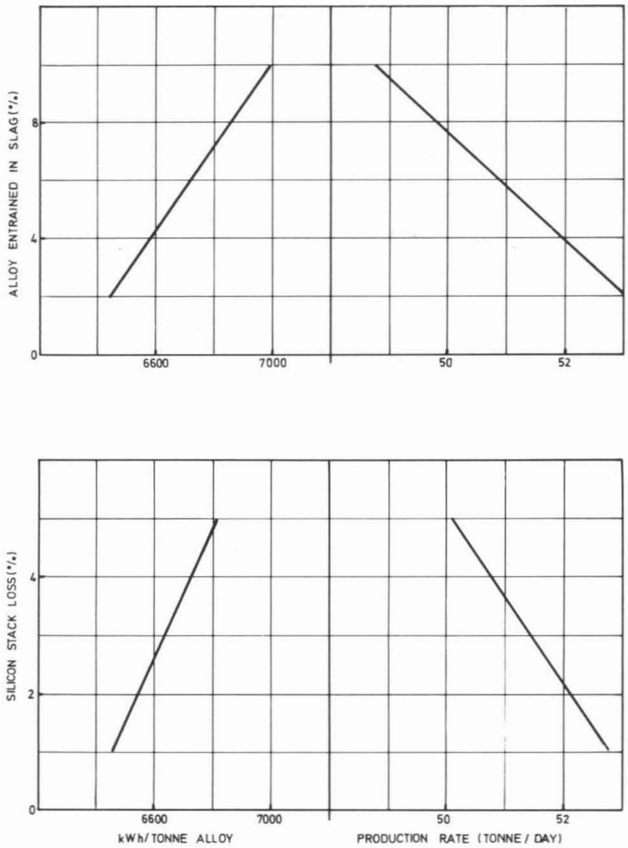

Figure 3

Relation of the alloy entrained in the slag and the silicon stack loss to the production rate of ferrosilicon-—chromium and to the power consumption

FINAL CONSIDERATIONS

The ferrosilicon—chromium operation described is based on the availability of high-grade, hard, lumpy chromium ore direct from the mines. Good-quality quartz is readily available near the refinery, and coke is supplied from the coke ovens at Wankie Colliery. Because of the electricity tariff obtaining and moderate labour costs, the operation is considered to be competitive.

Further work on the blending of chromium ores continues, and a comprehensive new metal-recovery plant is being constructed. Most important, also, operational knowledge continues to be acquired, so that problems arising are the more quickly recognized and dealt with, and consistency of production and metallurgical efficiency achieved.

DISCUSSION

Mr Grandjacques:*

Our experience with lumpy ores from other countries – Russia and Iran – when producing a silicon content of 44 per cent in the metal gives us higher yields of the order of 95 per cent, without any treatment of the slag for recovery of metal. Do you think this difference comes only from the difference in the silicon content or does it come also from the difference in the nature of the ores used?

Dr Clark:

We cannot claim a 95 per cent recovery, even with the use of jigs, and I am not in a position to comment on the reason for these high recoveries. Mr Grandjacques could perhaps help me in this respect.

Mr P. J. Delaney†:

(1) Dr Clark states that rotation is not 'normally' practised. Under what conditions would the furnace be rotated?
(2) Why have the tapholes been offset 12° from the nearest point of the electrodes?
(3) What is the weight of each batch?
(4) What is the size distribution of the recycled metallics from the concentrating plant?
(5) Is it correct to assume that all the coke fines are used in the clay mixture used for taphole sealing. If not, what do you do with the excess?
(6) How often is the coke moisture determined, and what variation is acceptable before the mix weight is altered?
(7) Do you ever 'sound' the electrode length by raising the electrodes? If so, how often?
(8) Having poured the molten furnace products into the second ladle, how long do you wait before teeming? What are the teeming temperatures?
(9) What are the tapping temperatures? What instruments do you use to determine this?
(10) What weight of metal do you retain in the tundish?
(11) The metal-recovery plant is recovering from 'old slag dumps'. Do you put all the tapped slag through the plant?
(12) What do you do with the metal fines, say minus 1/8 inch, from the dispatch department?
(13) When reporting slag silica contents, do you make allowance for the silicon carbide present?

Dr Clark:

(1) At one stage, our furnace was operated with the bowl oscillating, but we found no difference when compared with a stationary operation. It is now not possible to rotate our furnace, owing to the installation of new railway tracks.

(2) The position of 12° off centre of our tapholes was arrived at by trial and error. Secondly, this position suits the design of our rail-track system.

(3) Charges from the weigh flasks are based on 450 kg of chromium ore; the total weight of each charge, including reverts, is about 1200 kg.

(4) The size of the material is generally below ½ inch. Two of the new jigs operate on material between ¼ and ½ inch, and two jigs on material below ¼ inch.

(5) A limited amount of coke breeze is used for taphole sealing mixtures. The rest is stockpiled and, we hope, one day a use will be found for it.

(6) Coke moistures are normally taken twice per shift, and in abnormal conditions possibly every hour, so that adjustments to the furnace can be made. An adjustment is made for a significant variation of 1 per cent.

(7) The electrode length is measured only occasionally. Under normal steady furnace operation, electrode measurement is not necessary, and so the operation is carried out only when conditions are uncertain.

(8) We find that by decanting we can avoid the usual two-hour waiting time and obtain the same results. Secondly, by teeming immediately we can recycle the ladles more quickly.

(9) Temperatures are not normally taken. We expect, typically, 1650°C, but have found that it was difficult to correlate standing times, temperatures, etc., with the product analysis.

* Sofrem, France.

†Feralloys Limited, South Africa.

(10) If you refer to the paper and divide the total tundish weight by 279, this will give you the weight per tundish.

(11) When we have spare capacity, we look into the possibility of recovering metal from old slag dumps.

(12) The minus 1/8 inch metal fines are used as a mould lining or consumed in our low-carbon operation.

(13) As we only analyse for silicon in the slag and convert this result to silica, any contents of silicon carbide will cause an inflated reading of silica..

*Mr K. Yamagishi**:

(1) What kind of action is necessary for maintaining good electrode penetration?

(2) How would you raise the silicon content of the chromium silicide produced?

(3) During the production of chromium silicide, iron and chromium are generally reduced in the upper part of the furnace and silicon in the lower part, and therefore easily fusible ores should be an advantage. However, you use refractory ores. Could you comment on the mechanism of reduction?

Dr Clark:

(1) We have found that, with steady operation and the correct charge and secondary voltage, it is possible to maintain good electrode penetration. Our philosophy is that it does not pay to alter the mix too frequently. Attention must be paid to the blending system. We have had to replace our old system in order to obtain good control. By operating a check-in and check-out system, we can determine whether slag has been left in the furnace. It is essential to tap all the slag regularly.

(2) The manipulation of silicon in the final product depends principally on the quantities of quartz and coke added. Stack losses, however, are important because up to 3 per cent silicon can be lost via the stack at 42 per cent silicon-alloy level. In normal operation, stack losses are often, however, only 1 per cent. These data are fed into the charge calculation.

(3) We have found that wet weather, and fines in excess of 10 per cent, affect the operation, but we are fortunate in having refractory ores available. I would suggest that experiments using the frozen-melt technique would assist Mr Yamagishi in finding answers to his questions.

Mr C. Coetzer§:

I see in your paper that alloy and slag samples are taken from each tap.

Do you take samples at the taphole from the cast-iron moulds when teeming, or when breaking the alloy ingots manually, and why?

If you do not take regular samples from the cast-iron moulds, have you ever done so, and what were the results?

Dr Clark:

Spoon samples are taken from every tap, but analysis is carried out only twice a day, which means that the analysis represents an average of 4 to 5 taps, which are stockpiled according to analysis. When the charge to the furnace has been changed, more frequent samples are taken until the product analysis has settled down.

Mr B. Lund§:

Please comment on the gas evolution from the tapholes during the tapping of a silicochromium furnace.

Dr Clark:

A significant evolution of gas from the taphole is not inconsistent with good production. The fume in the casting bay, however, can be a nuisance. We intend collecting this taphole fume and diverting it into the furnace stack. It must be remembered that our furnaces are in the middle of Africa and the prevailing winds usually carry the fume away from any established communities. However, we are appreciative of pollution problems, and in time we do expect to install cleaning equipment.

*Mr J. Westly**:

What is the electrode current at normal operation? I notice that you use coke sized from about 15 to 40 mm. Have you tried to increase the furnace resistance by reducing the size of the coke?

Dr Clark:

The current at normal operation is 60 000 secondary amps, at a power factor of 0,86, with a secondary voltage of 168 volts. We appear to get a better operation with 15 to 40 mm, but in our new cutting plant we intend trying smaller coke sizes. Higher furnace resistance could give us a better power factor.

Dr R. Urquhart†:

Please elaborate on the reasons for finally choosing a pitch-circle diameter of 2,8 metres.

Dr Clark:

We have not experimented with adjustment over the full range of 2,55 to 3,05 metres. We have operated mainly in the middle of the range and have made only minor adjustments, which have shown little difference to our operations.

Dr K. G. Willand†:

(1) How do you explain the smaller standing time after tapping in the second ladle? How much time do you need?

(2) Do you use the slag for any other purpose?

Dr Clark:

(1) As I stated before, we have carried out tests of standing time versus temperature and analysis, but we had difficulty in correlating any of the results. We reladle for practical reasons, which allows us to teem immediately. The mixing of the slag and metal during the reladle practice may allow the carbides to collect in the slag more easily, as for a slag-washing process.

(2) There is little accepted use for our chromium—silicide slag at present, but this aspect is kept under review.

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