THE OPERATION AND CONTROL OF A SUBMERGED-ARC FURNACE TO PRODUCE HIGH CARBON FERROCHROME FROM PRE-REDUCED PELLETS

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(presented by Mr. Sciarone)

SYNOPSIS

The Process practiced at Consolidated Metallurgical Industries to produce high carbon ferrochrome utilizes only fine ores and cokes. These materials are pelletized and partially metallized prior to final conversion in a submerged-arc furnace to chrome alloy product. As process conditions change, pellets of varying quality are produced. These variations have markedly different effects on the furnace operation and are discussed in detail. Furnace control techniques to handle this charge material are therefore necessarily sophisticated.

1. Introduction

Fine chrome ore and coke are proportioned on beltweighers and fed by conveyer belts to a drier in order to reduce the raw material moisture content. The dried material is charged to ball mills where a fine powder is produced. The powdered material from the mills is mixed with bentonite and water. This moistened material is conveyed to pelletizing discs where pellets are formed. The pellets are transported by conveyer belt to a travelling grate where they are dried and preheated. At a temperature of approximately 1000^{0} C, the pellets are fed into a rotary kiln in which some of the chrome and iron oxides are reduced at a temperature in the region of 1200 - 1400^{0} C. The hot pellets are collected in a transfer car and weighed. Fluxes and lumpy coke are weighed out batchwise and charged onto each pellet batch in a container which is conveyed by an automatic crane to the charging floor at the top of the furnace building. The hot material is fed continuously from the charging bins to the electric furnace by a choked-feed system. The furnace is a modern closed type of standard design. Figure 1 illustrates the flow sheet at Consolidated Metallurgical Industries. Air pollution control has been documented previously (1).

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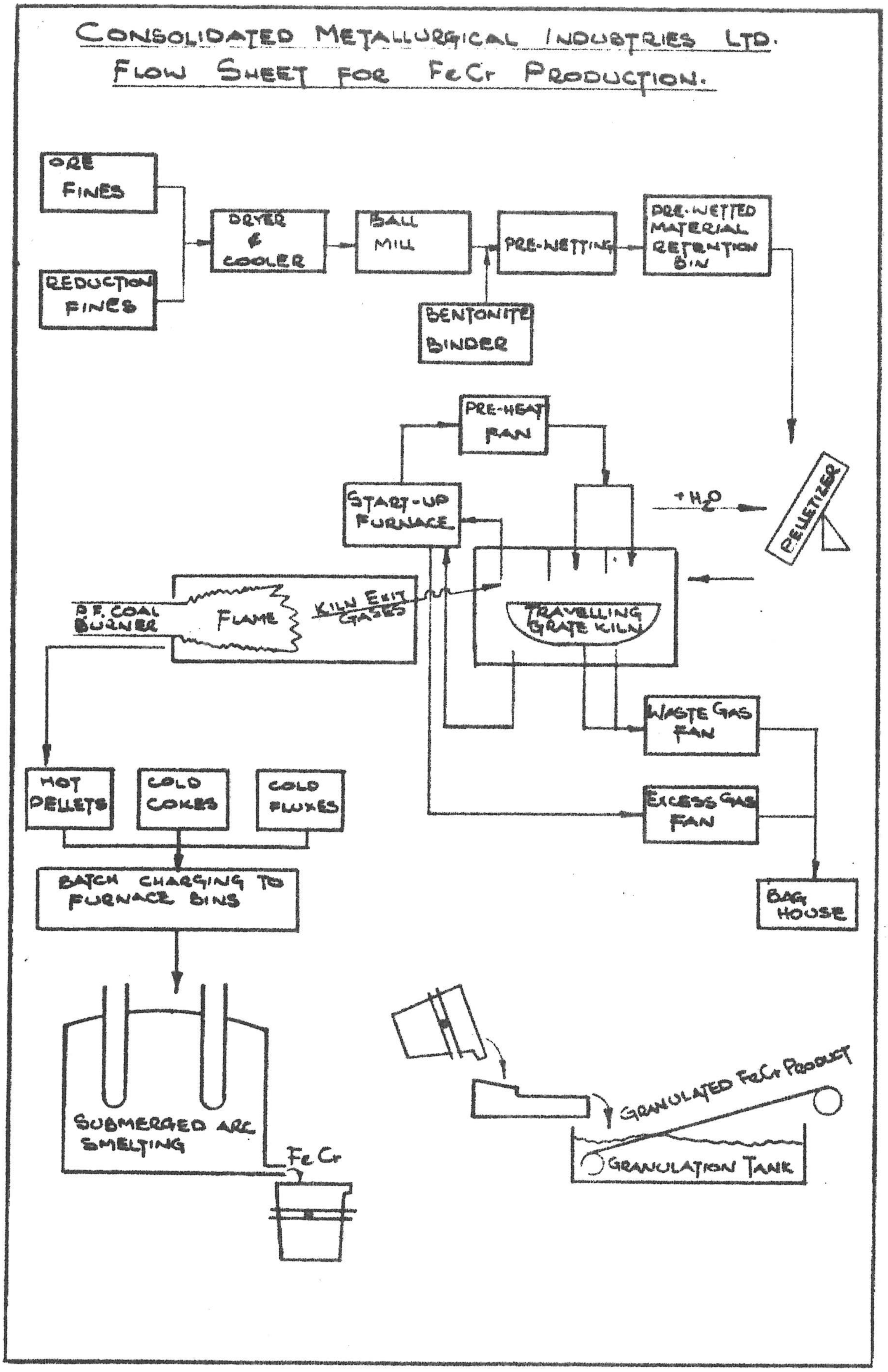
FIGURE 1


CONSOLIDATED METALLURGICAL INDUSTRIES LTD.
FLOW SHEET FOR FeCr PRODUCTION.
ORE FINES
REDUCTION FINES
DRYER & COOLER
BALL MILL
PRE-WETTING
PRE-WETTED MATERIAL RETENTION BIN
BENTONITE BINDER
PRE-HEAT FAN
START-UP FURNACE
+H2O
PELLETIZER
P.F. COAL BURNER
FLAME
KILN EXIT GASES
TRAVELLING GRATE KILN
WASTE GAS FAN
EXCESS GAS FAN
BAG HOUSE
HOT PELLETS
COLD COKES
COLD FLUXES
BATCH CHARGING TO FURNACE BINS
SUBMERGED ARC SMELTING
Fe Cr
GRANULATED FeCr PRODUCT
GRANULATION TANK

2. Grinding and pelletizing

The coke : chrome ore ratio, the mill product size distribution, the binder content and the water addition are the main factors that influence the quality. A strong pellet of adequate size (10 x 30 mm) would define quality. Figure 2 shows the relationship between binder content and pellet strength. A low binder content means a pellet that shatters easily in transit to the kiln. A high binder content results in pellet degradation in the rotary kiln. The coarser the material leaving the mill, the greater the binder content required for adequate pellet strength. Hence it may be seen that there is an optimum binder addition.

Figure 2

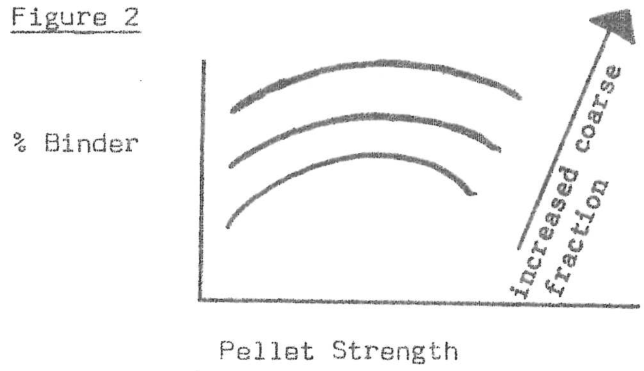


Figure 3 shows the relationship between binder content and the coke : chrome ore ratio for a constant pellet quality. The maximum strength line for a given binder content is that value over which the pellets would burst in the rotary kiln. An increasing carbon content of the pellets results in higher binder requirements to ensure adequate pellet strength. Hence it may be observed that there is a limit to the carbon addition if an adequate pellet strength is to be maintained.

Figure 3

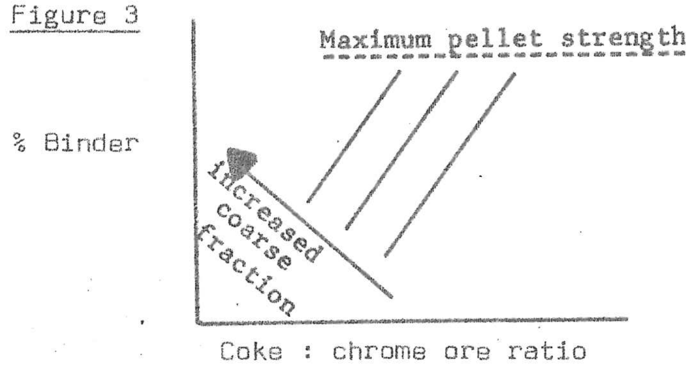
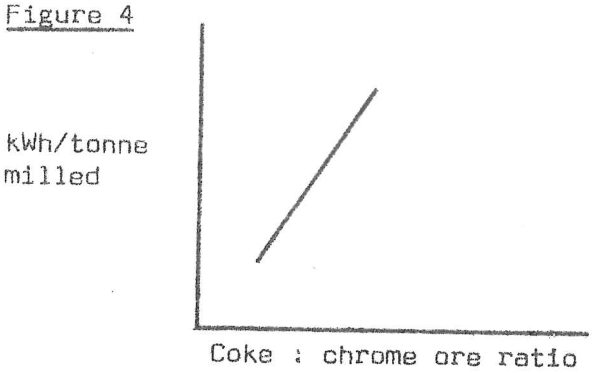


Figure 4 shows the relationship between the mill power consumption and the coke : chrome ore ratio. Hence an increase in the pellet pre-reduction level by an increase in carbon content escalates the power cost for milling and reduces the unit chrome throughput of the pelletizing plant. During weak market conditions, it is especially important to optimise the carbon content and lower production costs at the expense of output. In better times, the furnace capacity will determine the carbon level in the pellets.

Figure 4



3. Pellet pre-reduction

The level of pellet pre-reduction attained in the kiln operation may be affected by :

(i) initial carbon content of pellets,

(ii) sizing of the milled materials,

(iii) kiln operating conditions.

Figures 5 and 6 show pellet quality trends that have been observed in the C.M.I. operation of the SRC process.

Figure 5

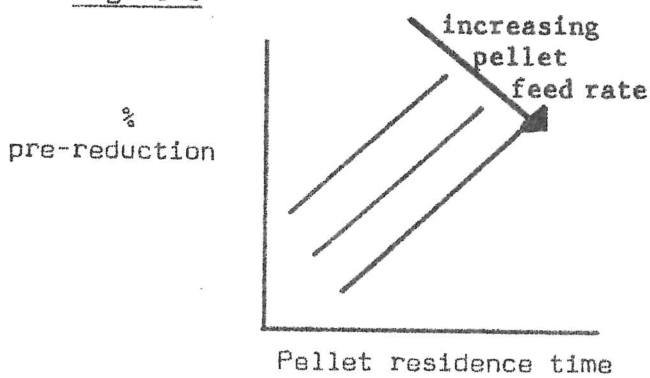
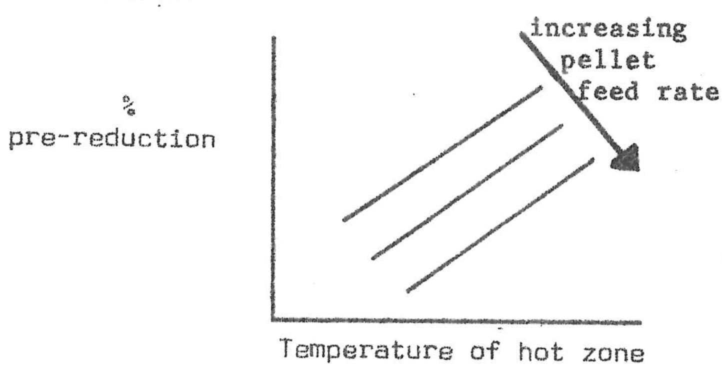


Figure 6



These trends may be affected by any variation in kiln fillage due to the gradual accumulation of accretions, which would adversely affect the level of pre-reduction. Considering constant kiln fillage however, an increase in the pellet throughput will reduce retention time. This will necessitate a higher hot zone temperature for the same pre-reduction level. There is a temperature limitation on the operation which means a throughput maximum at each pre-reduction level for constant kiln dimensions. There are many variables to be considered in the operation of the pre-reduction section. It is therefore essential to maintain a steady throughput so as to effect adequate process control and to maintain a hot pellet feed to the furnace.

4. Pellet quality

Table 1 shows the pellet quality variations that may be obtained by adjusting the control parameters of the SRC process. Each pellet type has widely differing effects on the furnace operation as may be seen from the carbon input levels.

TABLE 1

	PRE-REDUCTION	RESIDUAL CARBON	ADDITIONAL LUMPY COKE AS COMPARED WITH CATEGORY E	COMPRESSIVE STRENGTH	FURNACE RESISTANCE
A	ZERO	ZERO	280 %	LOW	LOW
B	6 %	0,5 %	220 %	AVERAGE	LOW
C	32 %	4,9 %	120 %	HIGH	SLIGHTLY LOW
D	50 %	5,3 %	80 %	HIGH	HIGH
E	60 %	2,5 %	100 %	HIGH	AVERAGE

CATEGORY A

This is the case of an ore pellet with no carbon or metallization. All the carbon requirements would be supplied in the form of lumpy reductants, which are generally less readily available and more expensive than fines. Compressive strength is low due to low kiln operating temperatures. The large : medium coke size ratio would have to be lowered dramatically from the normal levels for SRC materials to ensure adequate furnace loads. However, a low furnace resistance is still to be expected and a stable operation will be easily maintained. This situation has advantages if the pelletizing plant capacity has to be optimised, providing there is adequate furnace capacity. Photograph 1 shows the chromite ore pellet structure after heating to approximately 1200^{o} C.

CATEGORY B

In cases of local superheating in the kiln, partial re-oxidation may occur upon discharging which will result in a low final pre-reduction level and a high carbon burn-off rate. Compressive strength is average due to re-oxidation after exposure to high kiln operating temperatures. An excess of lumpy coke would be required to prevent the furnace moving to an undercoked situation. Hence the large : medium coke ratio would have to be lowered from normal levels to maintain a high power factor. Otherwise the operating resistance would fall and the furnace would become too stable. An increase in unit power consumption will result. Photograph 2 shows the pellet structure after heating to a temperature in excess of 1400^{0} C and then re-oxidizing most of the metallics. The chrome ore product has been reconstituted which is apparent when comparing with photograph 1.

CATEGORY C

This pellet condition arises from low kiln temperatures resulting in low chrome metallization and low carbon burn-off rates. The pellets have a high compressive strength despite the low kiln operating temperatures due to some metallization. Despite the high carbon level contained inside the pellets, the low pre-reduction means that additional lumpy coke must be added to the furnace to prevent an undercoked situation. A slight lowering of the large : medium coke ratio should maintain a high power factor. The higher carbon input will then only slightly lower the furnace resistance which can be accommodated for by adequate transformer capacity. An increase in unit power consumption will result. Photograph 3 illustrates the pellet structure arising from this situation. The small particles of metallic carbides may be observed and iron deficient chromite is apparent. The carbides are predominantly of the (Fe > Cr)C type which is to be expected as little chrome metallization has occurred.

CATEGORY D

With high carbon contents in the green pellet and low air flow rates through the kiln, a high pre-reduction may be achieved with high residual carbon levels. There are equipment restrictions on the green pellet carbon content as high CO generation will cause excessive heat concentration in the travelling grate and baghouse. The pellets are of high strength. Little lumpy coke will be required to maintain the [Si] specification. In fact the tendency is to overcoke the furnace so as to achieve electrical stability. An increase in the large : medium coke ratio should readjust the tendency for the power factor to drift towards unity. A high furnace resistance will persist, particularly after tapping when the load would have to be lowered for short periods prior to re-attainment of electrical stability. An increase in unit power consumption will often occur. Photograph 4 shows the resulting pellet structure. The growth of the metallic carbides may be noted when compared to Photograph 3. However the metallics are still in discreet particles. The increased chrome metallization results in some (Fe < Cr)C types along with the (Fe > Cr)C types.

CATEGORY E

This is the ideal pre-reduced pellet for submerged-arc smelting. Pre-reduction levels are high enough to minimise the unit power consumption. Carbon levels are low enough to afford flexibility in the large : medium coke ratio so as to maintain furnace stability. The pellets have high strength. A high furnace power factor is easily maintained despite any slight fluctuations in the pre-reduction levels and hence the [Si] content may be kept within a narrow range. As average furnace loads have increased, the large : medium coke ratio has been gradually increased to maintain the same furnace stability. Photograph 5 illustrates this pellet structure. The discreet metallic particles have coalesced and the residual chromite phase becomes lighter as it is further depleted of chrome and iron. Metallic carbides are predominantly of the (Fe < Cr)C type as further chrome metallization has occurred over category D.

Within operational limits, category E pellets with a pre-reduction level of 55 - 70 % and a carbon content of 2,5 - 4,0 % are produced on a regular basis. These variations have an effect on the furnace resistance which is monitored but usually not corrected for as there is sufficient transformer capacity for a steady MW load. Figure 7 shows the observed effects of changes in the pre-reduction level of category E pellets with furnace resistance. If high furnace resistances at high pre-reduction levels become unworkable, an upward adjustment of the large coke sizing would be required. Conversely low furnace resistances at low pre-reduction levels may be compensated for by a downward adjustment of the large coke sizing. These results are shown by the dotted line in Figure 7. The furnace resistance correlates with the volume of coke per unit volume of burden and not with the metallic content of the pellet.

Figure 7

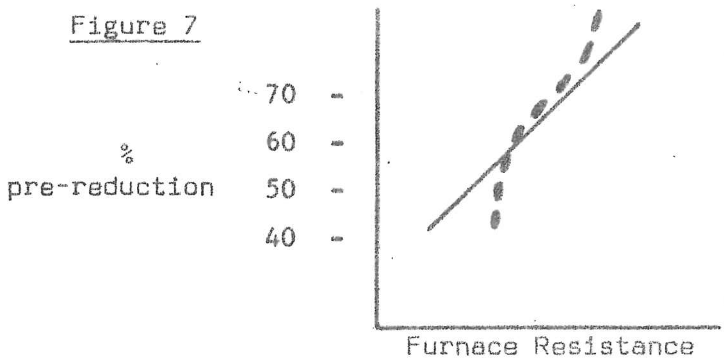
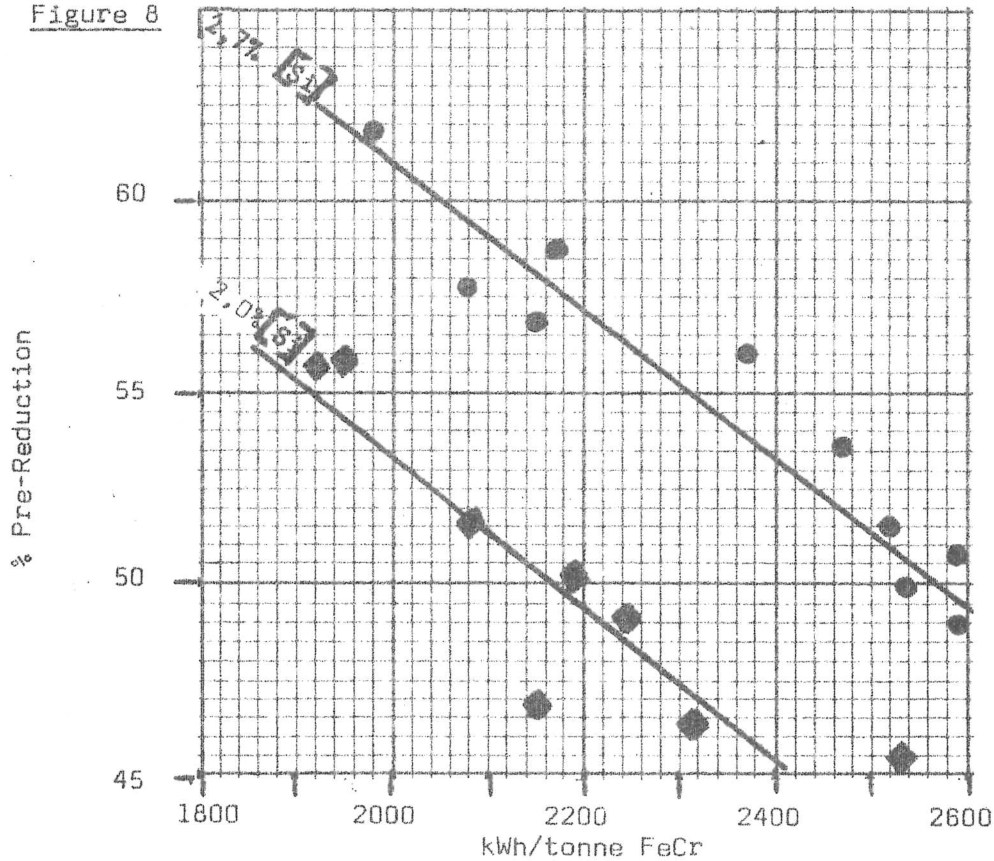


Figure 8 depicts data from the C.M.I. Plant for the period January - December 1979. The effect of higher pre-reduction levels is to lower the unit power consumption. Cold pellet operations would increase the power consumption by about 500 kWh / tonne FeCr.

Figure 8



The operational variables which have the most pronounced effect on the unit power consumption are :

(i) pellet hot rate,

(ii) input of non-SRC materials,

(iii) slag volume and composition.

The success achieved in smelting a partially metallized feed is due to the ability to maximise the production of category E pellets and to adjust the supporting furnace parameters in time when pellet quality changes to categories B, C or D. Thus consistent output results are ensured.

5. Furnace control

The operation of a submerged-arc furnace on a partially metallized charge is effectively controlled by careful attention to the following :

(i) Carbon inventory,

(ii) Electrode tip-to-hearth regulation,

(iii) Slag composition,

(iv) Lining control,

(v) Gas cleaning.

(i) The carbon inventory is maintained by periodic calculation of the furnace carbon requirements as the pellet analysis alters. Any change in the pre-reduction level necessitates a carbon adjustment. The silicon content of the FeCr product is a fast response indicator of the carbon inventory. Hence from silicon analysis of the product, coarse or fine carbon adjustments may be made. There is a correlation between the silicon content of the product and the furnace power factor which is also used as an early warning indicator of carbon inventory changes.

(ii) A working knowledge of electrode lengths is absolutely essential for effective tip-to-hearth regulation. The electrodes are moved evenly through a fixed distance during each tap cycle so as to accommodate the increase in height of the molten bath and to maintain the material melting rate. Heat flow and temperature indicators situated in the hearth, sidewalls, roof and gas stacks provide data from which to make any adjustments to the start and finish positions of electrode travel. Electrode consumption is based on the pellet consumption at each phase. Deviations may occur from the expected electrode consumption if the pre-reduction level changes or if cold pre-reduced pellets are introduced. Electrode length is regularly estimated to within 10 % on a 2500 mm length. Furnace resistance and reactance are continuously recorded while the Lissajous figure for each phase is displayed on request. These data assist in determining the stability of each phase. Instability causes severe arcing conditions at the electrode tips which will increase the electrode consumption.

(iii) The slag composition is adjusted for a slag liquidus temperature of approximately 1650° C. The gangue material in the ore and coke is fluxed with a blend of quartz, dolomite and limestone to ensure adequate fluidity and desulphurizing properties, Slag basicity has an effect on the crucible diameter in such a way that high basicities will cause the heating zone to move to the upper part of the furnace. If the slag liquidus temperature is allowed to increase above 1650° C, more power is required per tap to ensure good slag fluidity. Thus the unit power consumption will increase. The slag should not be permitted to become too fluid as this often results in a coke bed movement towards the taphole during tapping. Low furnace loads would then result until the melting of material re-established the coke bed.

(iv) Due to the fine balance that exists in the maintenance of a stable coke bed, there is an ever-present danger of the electrodes penetrating too deeply in order to maintain high furnace loads. Hence the need for effective lining control is essential for prolonged furnace campaigns. Details on this aspect may be obtained from a paper to be presented at the 38th Electric Furnace Conference (2).

(v) The furnace gases are cleaned by way of venturi scrubbers. The dust is collected in water which is pumped away to settling reservoirs. The gas is stored for use on the plant. The venturi system is controlled by pressure regulators which maintain a constant furnace roof pressure (1).

Table 2 details typical furnace operating data on the C.M.I. furnaces.

Table 3 details the product specifications.

Table 4 details the typical slag composition.

Table 5 details certain consumption figures.

Further information may be obtained from a paper presented at the 107th AIME Annual Meeting, 1978 (3).

TABLE 2

FURNACE OPERATING DATA

FURNACE LOAD	21 MW
FURNACE POWER FACTOR	0,90
ELECTRODE CURRENT	60 KAs
ELECTRODE-HEARTH VOLTAGE	130 Volts
FURNACE RESISTANCE	1,85 mΩ
OFF GAS TEMPERATURE	600° C
OFF GAS ANALYSIS	80 % CO

TABLE 3

METAL ANALYSIS

52,5 %	Cr
2,0 %	Si
8,0 %	C
0,030 %	S
0,015 %	P

TABLE 4

SLAG ANALYSIS

5 %	Cr_2O_3
1 %	FeO
54 %	$(SiO_2 + Al_2O_3)$
38 %	(MgO + CaO)

TABLE 5

PLANT CHROME RECOVERY	:	93 %
FURNACE POWER CONSUMPTION	:	2,0 MWh/tonne FeCr
ELECTRODE PASTE CONSUMPTION	:	2,5 kg/MWh

6. General

"As you have no pre-conceived ideas, you are not bound by tradition or established rules ..."

John Hays Hammond, Witwatersrand, 1893.

The complex nature of the C.M.I. plant employing the SRC Process to ferro-chrome production has shown that operator experience outside of the traditional ferro-alloy field has proved invaluable in the early successes of the plant. The areas of milling and pelletizing, grate and kiln operations, and gas reticulation, are not in the normal sphere of reference of the South African ferro-alloy producers.

7. Acknowledgments

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The authors would also like to thank the Managements of Johannesburg Consolidated Investments and Consolidated Metallurgical Industries for permission to present this paper and to E. Kinloch of the Group Research Laboratories for assistance with interpretation of the pellet microstructures.

8. Bibliography

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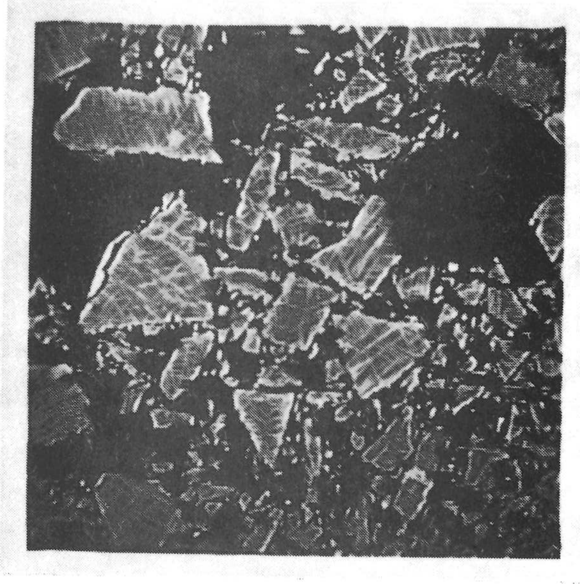
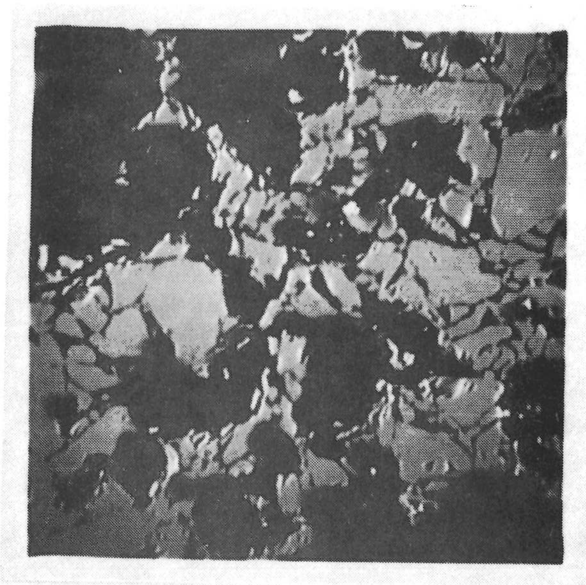
3. BENN H.J. *et al.* : The Control of an Integrated Ferro-Chrome Alloy Process. 107th AIME Annual Meeting. 1978.



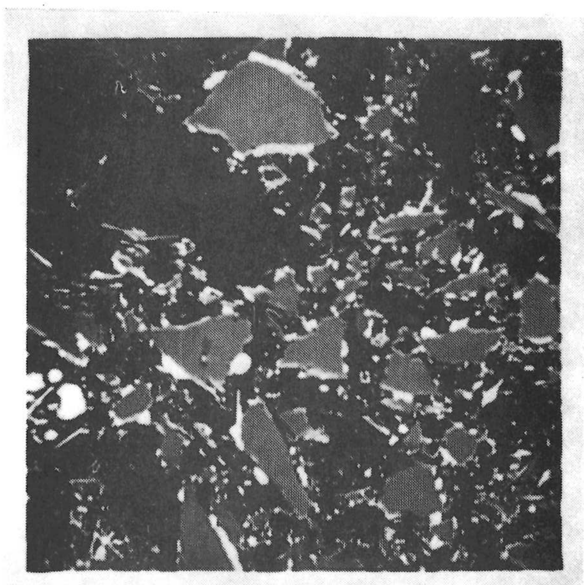
PHOTOGRAPH 1

Magnification : 300X



PHOTOGRAPH 2

Magnification : 300X

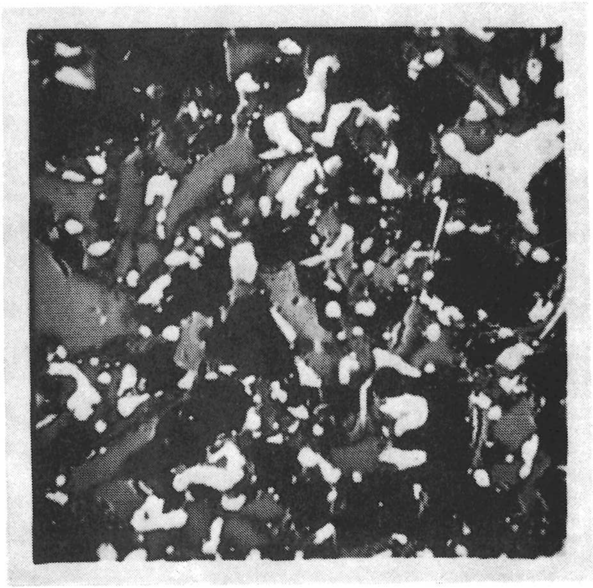


PHOTOGRAPH 3

Magnification : 300X

PHOTOGRAPH 4

Magnification : 300X



PHOTOGRAPH 5

Magnification : 300X

DISCUSSION

Dr. C. Finn*

Mr. Sciarone, as you are well aware, we are looking at the pre-reduction of Winterveld pellets at the Pyrometallurgy Research Group. We find that very high degree of pre-reduction can be achieved. Could you comment on the maximum level of metallization that could be used on submerged-arc smelting furnace with reference to coke-bed stability and, secondly, could you comment if 100% pre-reduction in the kiln were possible, could one use open arc melting effectively and economically?

Mr. M. Sciarone:

When the plant was started with pre-reduction pellets at times the operation did not go well, and we tapped slag and metal out of the kiln. So, in fact, we got 100% pre-reduction, but it was very difficult and I would say that it is impossible to control. We have been working on occasions at above 70%, but then the kiln operation was so difficult that we could not always maintain a 70% pre-reduction level to the furnace. Let us say that at 70% we had so far no problems. It depends how good is your control, how stable is the product you feed to the furnace. Then you use very little coke. If you say, we go further with the pre-reduction, say we manage some way to get the pre-reduction up to 90 - 95% then you cannot do a submerged-arc smelting and you go to arc, but with arc I think you would have to think twice as arc-smelting has its own problems.

Mr. C.N. Harman**:

I should like to know the frequency at which it becomes necessary to adjust the fixed carbon in the furnace while using these pre-reduced pellets in the actual practice and whether you use any oil in the process?

Mr. M. Sciarone:

We get an analysis every four hours and the operator takes his calculator and calculates the necessary changes of the carbon. That is just to maintain a certain carbon level in the furnace. As a result of the actual conditions to say whether you want to run 100% of theoretical, 105 or 95, that is maybe once in a couple of days that this is done at day time; but just to maintain that level that is required, that is done four hourly.

Mr. C.N. Harman

Do you provide covered storage for your coke?

Mr. M. Sciarone:

No, we only measure the moisture content in the coke and we make adjustments for that.

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Mr. C.N. Harman

What about any oil usage in the process?

Mr. M. Sciarone:

That is history. When we started, we started with 100% oil. Tests previously carried out showed that the usage of coal, pulverized coal, was quite feasible and in about a year's time, after start-up we were at about 90% coal and 10% oil. But it still was too much with those cost rises we experienced. It was quite easy, we modified the burner to such extent that it could work with 100% coal and it worked well and now have introduced the furnace gases and that even improved the operation further. So, in fact, we are using now only oil when the kiln is cold and has to be started up.

Mr. A. Das Gupta*

Normally for fine ores, there are two routes possible, one is the pelletization and the other is briquetting. Could you please give your considered opinion about which route you would recommend for the production of ferro-chrome?

Mr. M. Sciarone:

Both are possible and it depends on the location. In South Africa, there is another route, you just use the run of mine. So you do not do any agglomeration. But to come back to briquetting and pre-reduction, you can do both, any of them, and it depends on the availability of coal for example, the infrastructure you have, how easily are skilled people available, what previous experience you have, the cost of power. I cannot give you a straight answer. They both exist. Put it this way, Samancor is making a profit and CMI is also making a profit, each using of different route of agglomeration.

Dr. D. Slatter**

I would like to ask Mr. Sciarone a question that came up with another pelletizing operation which was used. As we all know, chrome ores are extremely abrasive in the fine state and this problem comes up particularly where one is involved with pelletizing and rotary kiln operations. What I would like to know is whether CMI has encountered any excessive wear problems on moving parts as the result of fine chrome ore dust in the atmosphere?

Mr. M. Sciarone:

Mr. Chairman, if Dr. Slatter looked well at our slides, there is no dust going into the air, we have a very good air pollution equipment, but concerning abrasion, yes, in that part where the material is still in a dry state, abrasion takes place. The milling itself is one of the more expensive parts of the operation and where we move the milled material which is still dry, you have to design your equipment very carefully so that either you have little abrasion or that maintenance of those parts that wear can easily be maintained at a very low cost. After we have made the pellets, from the pelletizer or after the water mixing, the wear is about nil. The maintenance is extremely low.

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* M.N. Dastur & Company (P) Ltd, India; ** University of Zimbabwe, Zimbabwe

Mr. P. Batty*

I would like to ask Mr. Sciarone: In the report on the analysis of slags, he refers to alumina and silica as a combined figure. Is this something peculiar to his operation and has he got the figures separately for us? A second question concerning the sizing of the coke and the ore fines after grinding: Do you particularly try and get these sizes to be comparable or do you take it as it comes out of the mill?

Mr. M. Sciarone:

Your second question is the easiest to answer. The feed of the mills is so controlled that the output material is 92% minus 200 mesh minimum. The reporting of the 2 out of 3 in the other components, that is done purposely. It is not usual but only for this occasion.

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* Union Carbide Management Services (Private) Limited, Zimbabwe