Manufacture and Use of Prereduced Chromium-ore Pellets

by Y. OTANI* and K. ICHIKAWA* (presented by Mr Otani)

SYNOPSIS

Showa Denko K.K. has developed a new process for the production of high-carbon ferrochromium. This is known as the SRC system. Since the distinctive features of the system have already been described, this paper confines itself to technical comments on the processes involved.

INTRODUCTION

A new mass-production system for high-carbon ferrochromium, incorporating a chromium-ore prereduction process, has been developed by Showa Denko K.K. (SDK). Named the SRC System, its course of development was as follows:

1968 1 kt/month shaft and rotary kiln, 4 MW open furnace, at Chichibu.

1970 5 kt/month grate and rotary kiln, 15 MW closed furnace, at Shunan.

1972 6 kt/month shaft and rotary kiln, 18 MW closed furnace, at Toyama.

Since the distinctive features of the SRC System have been reported by Ichikawa *et al.*[1] and by Kanoh[2], this paper refers to the technical points of each process in the system, introducing the achievements of many engineers who contributed to its establishment.

PULVERIZING AND PELLETIZING

The pulverizing conditions are selected so that the powder obtained is suitable for pelletizing and meets the requirements of stability and economics in all the subsequent processes – drying, preheating, prereducing, and smelting in the electric furnace.

Our laboratory tests show that a higher reduction rate can be achieved with pellets made from finer powder (Note 1 and Figure 1). However, as is well known, the cost of pulverization increases markedly as the pulverization required becomes finer (Figure 2 and Note 2).

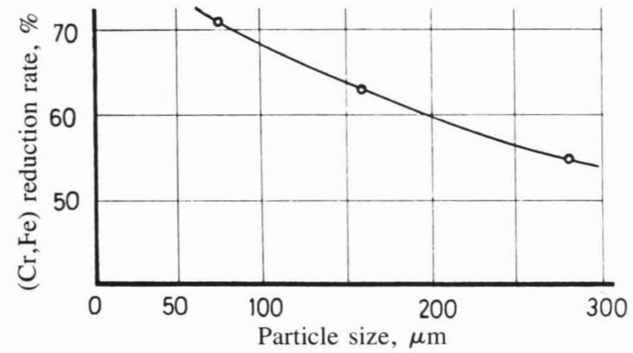

Figure 1

Effect of particle size on reduction rate

The effective heating surface of the pellet in a rotary kiln is only about one-seventh of its total surface area. Therefore, the heat-transfer rate in the kiln becomes the rate-determining factor for reaction velocity. Thus, the effect of fine pulverization is not great; that is, there is an optimum for the average grain size.

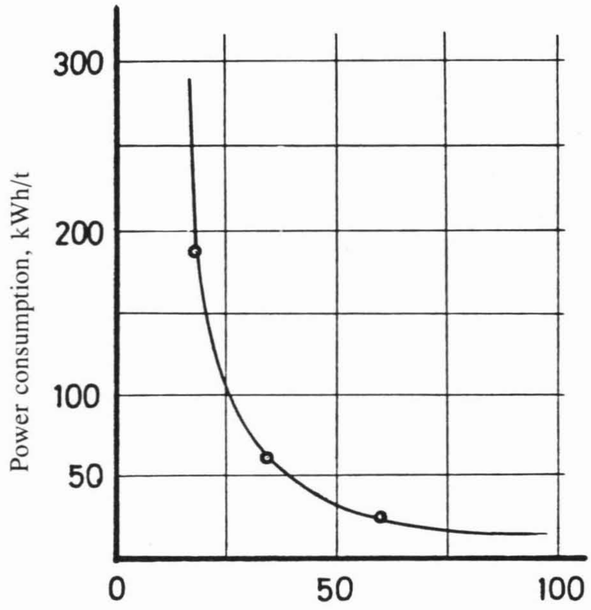

Figure 2

Power consumption of SRC grinding process

As shown in Table 1, although the pulverizing properties of chromium ore are considerably different from those of carbonaceous materials, the pulverization of mixed material has been adopted for the SRC System for the following reasons.

(1) Capital, maintenance, and power costs are low. One pulverizer will suffice, no mixers are necessary, and the number of feeder conveyors required is small.

(2) There is no danger of coal-dust exploding when carbonaceous materials are being pulverized.

(3) As the difference in the volume grindability (kW/m^3) between chromium ore and carbonaceous materials is not so large, and as the mixing ratio of chromium ore and carbonaceous material is close to 1 by volume, it is expected that any lowering in mill performance and any segregation resulting from these differences will be small.

Anthracite is generally cheaper and easier to pulverize than coke, and its pelletizing property is fairly good (Note 2). However, the pellets are apt to disintegrate in the kiln when anthracite is used. This phenomenon is due to the fact that, when the pellet is heated, the anthracite in its outer part and that in its inner part do not expand and

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Table 1
Grinding characteristics

	Cr ore		Carbon matter					SRC mixed
			Breeze coke			Anthracite		powder
	(1)	(2)	(1)	(2)	(3)	(1)	(2)	
RF	0,84	0,67	0,905	0,855	0,881	0,92	0,79	0,70
F_{80}, μm	530	365	1925	3550	2400	3190	2160	490
P_{80}, μm	131	134	134	132	143	128	130	132
Q_{80},g	1935	1901	559	756	609	667	760	1544
Gbp,g/rev	2,06	2,99	0,43–0,46	0,47–0,51	0,234	0,99–1,05	0,29	1,95
Wi,kWh/t	15,6	16,8	41,9–44,5	34,5–37,2	74,8	19,2–19,9	58,8	19,5
Apparent density, g/ml			0,80	1,08	0,87	0,95	1,09	—
Specific density, g/ml			2,03	1,96	2,13	1,40	1,52	—

shrink simultaneously with each other. Special consideration should be given to the solution of this problem.

As can be assumed from Yoshimura's[3] opinion on the pelletizing behaviour and mechanism of chromium ore, the pelletizing conditions of a mixed powder are of considerably narrow range.

Our several years of experience in pelletizing various kinds of chromium ores and carbonaceous materials at our commercial plants and our hypothesis on the pelletizing mechanism permit the correct selection of ores and carbonaceous materials and an accurate determination of the pulverizing and pelletizing conditions suitable for the raw materials used.

DRYING AND PREHEATING

The green pellets are strong enough to be handled, provided that they are not dropped from a height or subjected to pressure.

However, their strength diminishes as they become drier. Therefore, the following two methods have been used for drying and preheating:

(1) net conveyor as dryer, and shaft kiln as preheater, and
(2) the travelling-grate kiln.

Although method (1) brings savings in capital, power, and fuel costs, powdering of the pellets is somewhat marked. The travelling-grate kiln can treat pellets of low strength, and its maintenance cost is low; but its capital, power, and fuel costs are somewhat high. The choice between the two methods depends upon conditions such as the diversity of raw materials, the power cost, and the skill of the workers.

Excess oxygen in the preheater must be avoided since it brings about caking or disintegration of pellets by its reaction with the carbon in the pellets.

PREREDUCTION IN THE ROTARY KILN

Pellet reduction takes place in about one half of the area of the rotary kiln (Note 3). Since they exist in spinel, iron oxides in the chromium ore react directly with carbon as shown[4] by the following equation:

$$(Fe,Mg)\,O\cdot(Fe,\,Cr,\,Al)_2O_3+C\rightarrow (Fe,\,Cr)_7C_3+MgO\cdot Al_2O_3+CO.$$

While it has been said[5] that a non-oxidizing atmosphere is desirable as a reducing condition in the kiln, there is little oxidation of pellets by O_2, CO_2, and H_2O since they are protected by the carbon monoxide that emerges from the inside of the pellets during the reduction reaction (Note 4).

The half of the kiln occupied by the feeding side is the preheating area. In the SRC System, about 30 per cent of the carbon in the pellets is lost by combustion, which occurs mainly in the border area between the preheating and the reduction areas.

In the border area, which is a short distance from the tip of the flame, the supply of energy is not sufficient to activate the reduction reaction. Because some oxygen is present, the pellets are oxidized from their surface, and the resulting energy causes the temperature of the pellets to rise to that necessary for the reduction reaction.

The outer shell of oxides formed at this time is sintered in the reduction area, giving strength to the pellets and preventing further oxidation.

We have obtained pointers for solving various kinds of operational troubles that are caused by fluctuations in external factors, because we were able to obtain the standards for the design and operation of the kilns from broad measurement, analysis, and simulation of the transfer of heat and substances in the rotary kiln, and from the accumulation of daily experience in manufacturing (Notes 3 to 6).

SMELTING IN THE ELECTRIC FURNACE

Prereduced pellets (SRC pellets) are continuously charged into the electric furnace in a hot state after being mixed with additional lumpy coke and ore to form slag. The saving in power consumption from hot charging is from 400 to 500 kWh per tonne of alloy.

The consumption of expensive lumpy coke in the SRC System is less than half that in conventional processes. Owing to this fact and to the easy melting of SRC pellets, the SRC System tends to make operation of a submerged type of furnace difficult.

Excessive melting of the charge temporarily brings about decrease in the yield of chromium and an increase in the sulphur content of the metal. If this situation is left as it is, the silicon content of the metal will increase, and it will become difficult to take out the slag.

The methods of clinical examination and treatment[6] used for silicon reduction furnaces are also effective for SRC furnaces. We obtained a great deal of knowledge about the coke bed from the operation at the Shunan Works, and were able to achieve stable operation of the furnace (Note 7).

Another important problem relating to furnaces is erosion of the furnace bed and walls by metal or slag. While there are many opinions on the law of similarity and the fixing of dimensions for the scaling up of furnaces, there seem to be none on designs, dimensions, and materials for the lining.

By utilizing the heat flow meter developed by Sumigama *et al.*[7], we were able to remedy the critical stoppage of electric-furnace operation at the Shunan Works caused by the erosion that appeared on the bed of the furnace five months after start-up. Full and smooth operation is continuing at the Works. From this experience, a method for the examination of the lining with the heat flow meter and a new system for the design of the lining were proposed.

SIZING AND REFINING OF METAL

The water-granulated metal shots that were developed at the Toyama Works and commercialized at the Shunan Works are beginning to obtain recognition on the market. Table 2 compares the characteristics of metal shots with those of ordinary metal.

Table 2

Composition of high-carbon ferrochromium

	Hydraulic shots				Conventional metal	
Size, mm	20–10	10–6	6–3	3F	150–10	
%	18	30	40	12	—	
C,%	7,5 –8,5				4–6	6–8
H,p.p.m.	5,7–10,3	5,8–10,5	5,9–9,1	6,9–8,2	5–10	7–15
N,p.p.m.	40–116	40–120	60–104	60–123	200–460	58–230
O,p.p.m.	268–488	260–423	288–425	305–401	370–680	170–430

The advantages of the shots method are as follows.

(1) Handling by machine is easy, thereby saving labour.
(2) Since the quality of the product is uniform, there is no segregation of the components as in metal that is cast.
(3) Only a small building is required for the handling of a large volume of metal.
(4) Being simple, the processes from molten metal to commercial product can be completed within one hour. There is no heat and no noise pollution of the environment.
(5) The yield of the commercial product is as high as 98 per cent.
(6) In view of the above points, products of a high utility value can be manufactured at low cost.

Since the metal manufactured at the Toyama Works is supplied to many consumers, a process has been incorporated to decrease the carbon and sulphur contents and so meet the requirements of consumers.

A 7-tonne low-frequency induction furnace has been installed, enabling high-carbon ferrochromium of a maximum sulphur content of 0,01 per cent to be manufactured. Furthermore, the operation of a 10-tonne oxygen-blowing converter will be started in August 1973, thereby enabling us to supply 2 kilotonnes per month of medium-grade ferrochromium (carbon content 3 to 4 per cent).

The metal tapped from the electric furnace is treated in the abovementioned converter in a molten state so that it will meet the new demand for medium-grade product from stainless-steel manufacturers who have adopted the Witten and AOD processes.

Table 3 shows the properties of low-sulphur and medium-carbon ferrochromium.

DIRECT SMELTING OF SRC PELLETS

Since the operation of the submerged-type furnace becomes difficult when the reduction rate of SRC pellets is raised, we are controlling the reduction rate to under 70 per cent for the current SRC System[8].

High-reduction pellets are smelted direct with equipment similar to the open-arc furnace for steel manufacture. In this case, special consideration has to be given to the dimensions of the equipment and to operational methods since the quantity of slag is large and the generation of carbon monoxide is also substantial.

This process makes it possible, by changes in operational method, to manufacture metal of three different carbon contents: 6 to 8, 4 to 6, and 3 to 4 per cent.

MERITS OF SRC SYSTEM FROM VIEWPOINT OF RESOURCES UTILIZATION

Table 4 compares the consumption of energy and ore in conventional processes with that in the SRC System.

a. The consumption of total energy in terms of fuel oil is smaller in the SRC System than it is in conventional processes. Since two-thirds of the power in Japan is generated by thermal energy (chiefly fuel oil), the power consumption for the above was calculated in terms of fuel oil, on the assumption that all power is generated at a thermal efficiency of 38 per cent. Since the carbon monoxide in the kiln is used as captive fuel in the SRC System, there is a saving in total energy. Furthermore, the possibility of using the carbon monoxide generated in the electric furnace makes the system especially excellent in this regard.
b. As the recovery of chromium in the electric furnace

Table 3

Specification of low-sulphur and medium-carbon ferrochromium

	Low-sulphur		Medium-carbon	
	Aver.	Std devn	Aver.	Std devn
Cr	57,2	0,9	61,8	0,80
C	7,5	0,25	3,3	0,32
Si	2,2	0,45	0,3	0,06
P	0,020	0,0015	0,03	0,002
S	0,009	0,0015	0,03	0,007

Table 4

Material and energy requirements for the production of high-carbon ferrochromium

Item	SRC system	Conventional system
Cr ore consumption, kg/t	1853	2020
Cr_2O_3 content in ore, %	44,44	49,35
Cr content in metal, %	53,07	62,05
Cr recovery, %	94,2	90,9
Electric power, kWh/t		
for furnace	2116	3840
for motor and others	354	210
Breeze coke, kg/t	388	—
Lumpy coke, kg/t	227	480
Heavy oil l/t	208	24
Fuel equivalent (heavy oil), l/t		
Electric power*	570	917
Burnt coke†	108	—
Heavy oil	208	24
Total	886	941

*0,2263 l/kWh (heat efficiency 38%)
†0,8 l/kg x (388 + 227 − 480)

is as high as 94 to 95 per cent in the SRC System, the unit consumption of chromium ore is small.

c. Low-priced chromium ore, coke, and anthracite in a powdery state, for which there had formerly been little use, can be used fully.

As stated above, the SRC System makes it possible to save or make fuller use of ore resources. From this point of view, we believe that the SRC System will consolidate its position as an improved method for the manufacture of high-carbon ferrochromium.

ACKNOWLEDGEMENTS

While it goes without saying that the development of the SRC System resulted from the cooperation of many engineers, we wish to take this opportunity of expressing our deep appreciation to those who contributed their unpublished data to the preparation of this paper.

NOTES

1. Data on the initial stages from crushing to prereducing
M. Yamanaka, F. Kusama, S. Nakajima.
2. Study of the mechanism of pulverization and pelletizing
R. Yoshimura, T. Shoji.
3. The behaviour of pellets in a rotary kiln
M. Yamanaka, M. Tanaka, Y. Suzuki.
4. The reaction behaviour inside pellets
S. Sumigama, J. Ito, H. Kawashima, K. Nishimura.
5. Thermal analysis of the rotary kiln
S. Sumigama, Y. Arakawa.
6. Movement of pellets in rotary kiln
K. Nishimura, Y. Kojima, S. Onodera.
7. Analysis of the electric furnace
K. Kagata, T. Yoshida, T. Takahashi, K. Shirai, K. Ushiyama.

REFERENCES

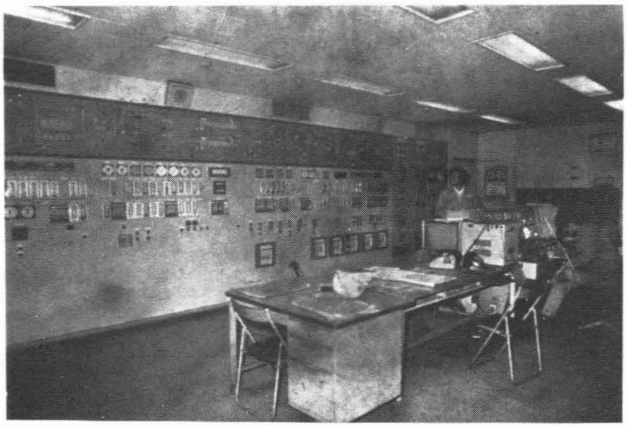
1. ICHIKAWA, K., *et al. J. Iron Steel Inst. Japan*, vol 57. 1971, pp. S363-364.
2. KANOH, Y. Solid-state reduction of chrome ores. Ferro alloys: special issue. London, Metal Bulletin, 1971. pp. 83-91.
3. YOSHIMURA, R., *et al. Ferroalloy (Japan)*, vol 22, no. 1. 1973 p. 14.
4. SAGA, J., *et al. Ferroalloy (Japan)*, vol. 21, no. 1. 1972. p. 6.
5. DOUGLAS, J.C., Chromium-containing alloy addition agents for electric-furnace steelmaking. *U.S. Pat. no. 2,883,278*, 1959.
6. OTANI, Y., *et al.* UIE VI, no. 112, 1968.
7. SUMIGAMA, S. J. *Iron, Steel Inst., Japan*, vol. 55. 1969. p. S456.
8. OTANI, Y., *et al. Ferroalloy (Japan)*, vol. 22, no. 1. 1973. p. 46.

In presenting the paper, **Mr Otani** spoke as follows.

I am happy to have this opportunity of telling you about our SRC system. This is a new system for the high-efficiency mass production of high-carbon ferrochromium. A prereduction process for the chromium ore is incorporated in the system.

I should like to show you some pictures of our plants, and present a brief introduction of the system.

Slide 1



This is the central control room of our Toyama plant. You can see the graphic diagrams at the top of the panel. I shall try to indicate the material flow by using this diagram.

Fine ore and breeze coke are separately dried and stocked. They are then weighed, mixed, and ground together in tube ball mills. The reason for the mixed grinding method is explained in the paper.

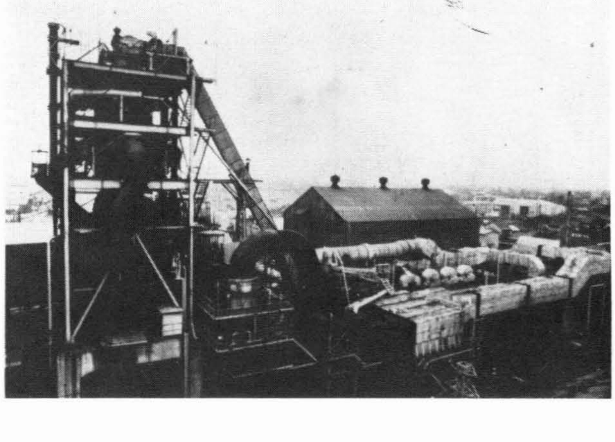
The mixed fine powder and the binder are weighed, mixed, and some water is added. The material is then sent to pan-pelletizers and is formed into green pellets. The green pellets go to band dryers, and then to a shaft kiln for preheating and are finally partially reduced in a rotary kiln.

The reason that we chose band dryers and a shaft kiln for the Toyama plant, instead of a LEPOL kiln or a travelling-grate kiln as at the Shunan plant, will be dealt with later.

The hot pellets, which have been prereduced up to 60 per cent, are fed with quartz ore and lumpy coke into an 18 MW closed electric furnace with a bag filter serving as the dust collector.

Slide 2

On the lower left-hand side, you can see the tail part of the rotary kiln. It is 4,8 m in diameter and about 70 m long. This high structure is the shaft kiln. The source of its heat is, of course, waste gas from the rotary kiln. The pellets are heated up to several hundred degrees centigrade in this kiln.



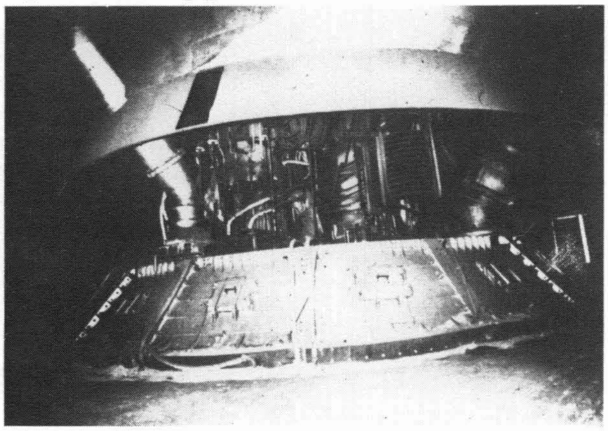
On the right-hand side are the band dryers for green pellets. Waste gas from the rotary kiln is also used in these dryers as heat source.

Over there, is the building for the pelletizers and the tube ball mills.

Slide 3

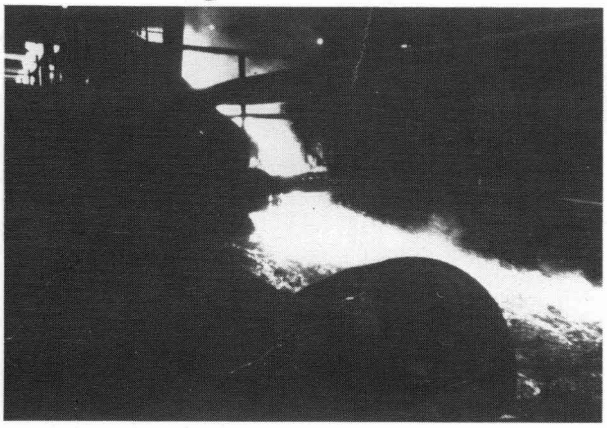
This is the upper part of the electric furnace. The large object on the right is the take-off pipe for furnace gas, and the small one is feeder for the furnace.

The material is, of course, fed in a hot state, and there is a total of six feeders. There are three Soederberg electrodes with a diameter of 1,4 m. The dimensions of this furnace have been decided on the basis of a new design system that takes lining life into consideration. This is explained in the paper.



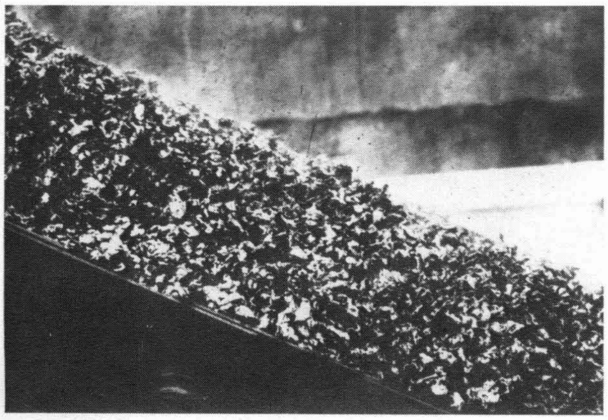
Slide 4

Molten ferrochromium tapped from the furnace is poured into a pool of water and is formed into shots. It takes only a few minutes for molten metal at a temperature of 1600°C to change into shots.



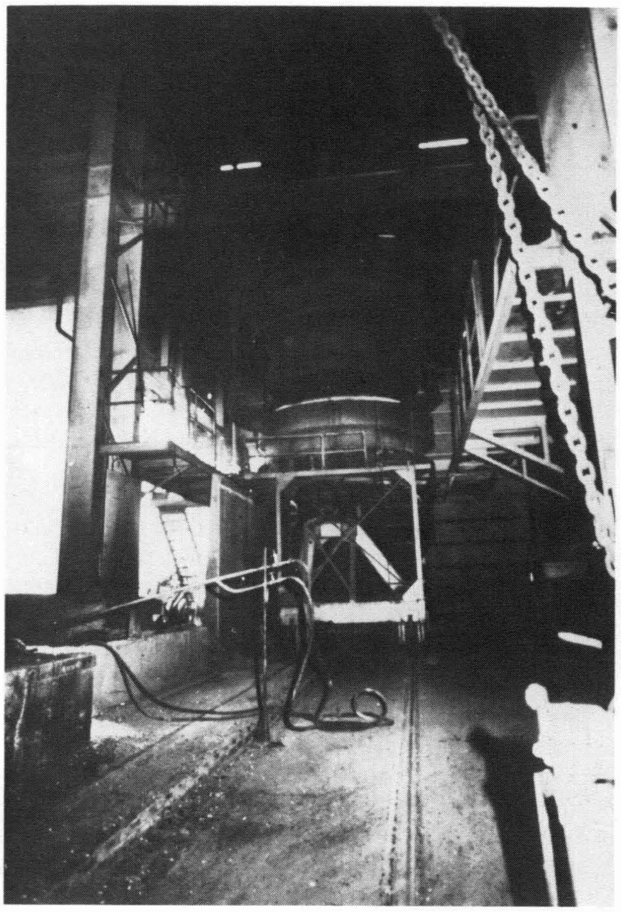
Slide 5

These grains are shots made by the hydraulic method. The shots are from 2 to 20mm in size. The power of the water jet determines their size distribution.



Slide 6

The Toyama plant has converters with an oxygen-blowing lance for medium-carbon ferrochromium. This is the converter most recently added to the SRC plant. Its capacity is 20 kilotons a year. Even some stainless-steel makers who are using the AOD or VOD system still require such a medium-grade product having a carbon content of between 2 and 4 per cent.



Slide 7

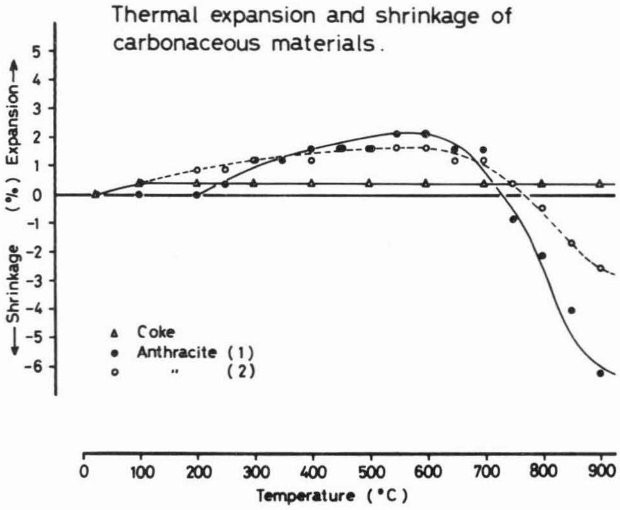
We can use various kinds of carbonaceous matter as the reductant for the pellets. As for the anthracite in this table, for instance, it seems preferable in view of its good grindability, low work index by Bond's method, and very low abrasion index.

Characteristics of various carbonaceous materials

	Breeze coke			Anthracite		Remarks
	(1)	(2)	(3)	(1)	(2)	
Fixed carbon %	88.0	73.7	87.1	78.0	79.0	Industrial analysis
Apparent density g/ml	0.80	1.08	0.87	0.95	1.09	
Specific density g/ml	2.03	1.96	2.13	1.40	1.52	
Work index KWH/s.t	41.9 ~44.5	34.5 ~37.2	74.8	19.2 ~19.9	58.8	by Bond's method
Grindability g/rev	0.43 ~0.46	0.47 ~0.51	0.23	0.99 ~1.05	0.29	
Abrasion index	—	—	100	1.1	7.7	
Price ¥/F.C.-t			12,200	17,400	15,600	in Japan

Slide 8

The well-known heat characteristics of anthracite, namely, expansion followed by strong shrinkage, makes its use as a reductant for the pellets difficult.



I think that, when the pellets are heated up to about 800°C in a rotary kiln, some shrinkage is caused in them by the anthracite's heat characteristics and some cracks are caused on the surface of the pellets as well as inside.

Carbon combustion in the pellets steps up the crack formation in the kiln, causing the pellets to be broken into pieces.

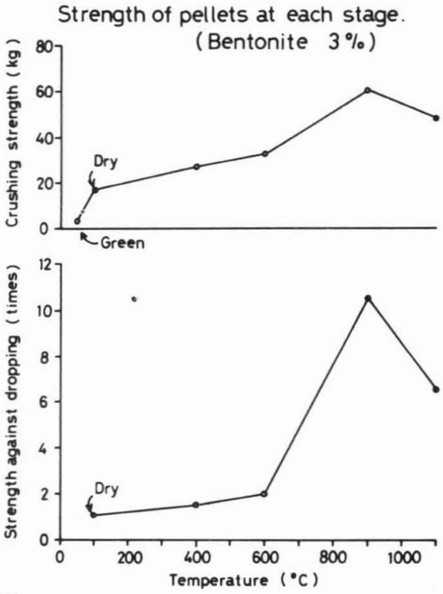
The increase in the surface area of pellets caused by this breakdown accelerates carbon combustion. Repetition of such breakdown and carbon combustion causes rapid collapse of the pellets into a sandy form.

It is necessary to contrive a special means for the use of anthracite as the reductant.

Slide 9

The strength of the pellets changes according to their temperature, as you can see in this figure. As for dropping strength in the range from a dried state to 500°C, the pellets are very weak. For this reason, the travelling grate or LEPOL is preferable for drying and preheating.

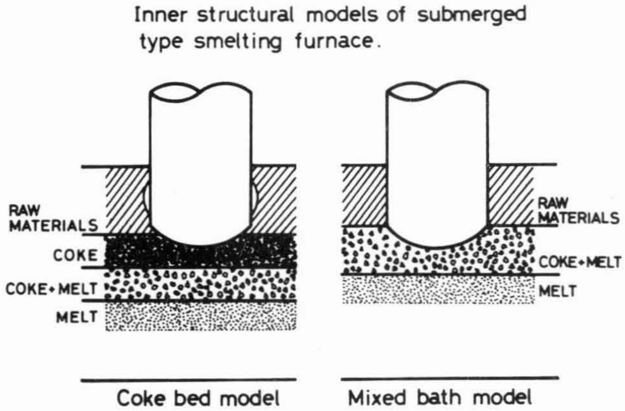
But separate equipment such as a band dryer and shaft kiln have been used at the Toyama plant because of their high heat efficiency and lower plant cost.



Slide 10

One of the difficulties of our system is found in operation of the electric furnace. To benefit from the merits of hot-charging, it is preferable to use a closed furnace, but it is somewhat difficult to make corrections when the furnace begins to function poorly. Moreover, the ratio between residual carbon and oxygen-fixed chromium and iron in the pellets is subject to change from hour to hour. But it is hard to add carbon in the proper quantities to conform fully to these every hour.

Another problem is the use of lumpy coke in smaller lots to charge the electric furnace. We furnace engineers or operators often find imbalances in load between the three electrodes, gas blowing around the electrodes, or faulty slag discharge. I think they are caused by unsuitable formation of the coke bed. It is necessary to keep the coke bed in a suitable state. Without proper formation of the coke bed, the furnace functions poorly.



I shall conclude with the merits of the SRC system, which are as follows.

(1) Electric power consumption is lowered to about one-half that of conventional methods.
(2) More easily obtainable and cheaper materials such as friable ore and breeze coke are fully used at high efficiency. Moreover, low-grade chromium ore with a lower ratio of chromium to iron is used economically. By means of prereduction, the iron is fully reduced in a rotary kiln, without the use of high-cost electric power.
(3) For mass production, it is guaranteed to provide a high recovery of chromium – up to 95 per cent – on a stable basis. Additional equipment for the refining of molten metal can help to enlarge the market.
(4) As mentioned in Table 4 of our paper, the total equivalent fuel consumption of SRC is lower than in conventional processes. We are now making development efforts to use powdered coal as fuel in the rotary kiln. If this approach is successful, the figures of Table 4 would be changed to those indicated below:

Table 4 (revised)

Fuel equivalent (Coal*)kg/t	SRC system	Conventional system
Electric power†	824	1 500
Burnt coke	180	—
Heavy oil	347	30
Total	1 351	1 530

*6 M-cal/kg of coal
†0,39 kg of coal/kWh

(5) Since we have abundant experience and test data, we are able to prepare a design that is highly suited to the conditions of the site wherever it may be.

DISCUSSION

*Dr D. Slatter**:

What is the carbon content of the pellets fed to the kiln,

*Institute of Mining Research, Rhodesia.

and what is the depth of the pellet bed? Also, what are the temperature and strength of the pellets?

Mr Otani:

The carbon content of the pellets charged to the kiln ranges from 70 to 100 per cent of the theoretical. Theoretical carbon is that amount required to reduce the iron oxide and chromium oxide in the ore to $(Cr,Fe)_7C_3$. Only pellets are fed to the kiln, no coal being added separately in any attempt to control the reducing conditions in the kiln. Figures relating to the depth of the pellet bed may not be disclosed. Temperature measurements in the kiln are very difficult but it is estimated that the maximum pellet temperature is in the range 1200 to 1400°C. The strength of the pellets appears to be in the range of 25 to 50 kg.