

The Importance of Chromite Pretreatment in the Production of Ferrochromium

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This paper describes the development of pretreatment methods for chromite fines in order to achieve efficient and competitive ferrochromium production. Owing to low-grade raw materials, relatively high energy costs, and demanding environmental legislation, Outokumpu has been forced to develop the most economical methods to be able to maintain viable ferrochromium production in Arctic conditions. The methods investigated and tested by Outokumpu are briefly discussed in this paper, including agglomeration, plasma technology, and prereluction of chromite. The methods are compared based on operational experience on a commercial scale, as well as on results from laboratory and pilot-plant tests. The process currently being used by Outokumpu Chrome is also briefly described.

Introduction

Outokumpu's start in ferrochromium production in Finland at the end of the 1960's was modest. A large ore deposit, but of low chromium content, had been found near the city of Kemi. With a Cr/Fe ratio of only 1,5 to 1,6, it was clear that this ore could not be used directly for the production of the quality of ferrochromium required by the steelworks at that time.

A complex concentration route for the chromite, involving upgrading of the ore and metallurgical enrichment of the chromium, was developed by necessity, so that the ferrochromium could be sold. The complexity and low operational availability of this production chain could have brought Finnish production to a halt at the beginning, but a technical breakthrough in the steel industry came to the rescue. The advent of the AOD converter in stainless-steel production made possible the use of ferrochromium that is low in chromium and high in carbon.

The expensive investigations and tests in the early years were not a waste of money, because at that time one basic fact was hammered into our heads: a reliable, continuous operation in ferrochromium production is the lifeblood of the business.

The conditions in Finland did not favour this type of industry, because electricity was (and still is) more expensive than that of our main competitors. A suitable reductant is not produced in Finland. Labour is expensive, although the standard of education is high, making automation possible to a high degree. Finland and the whole of northern Europe are world leaders in environmental and industrial hygiene demands. In view of these constraints, including the location of the mine and the factory (near the Arctic Circle), it is easy to understand that the maintenance of a profitable operation requires continuous research and development.

Many attempts have been made to improve and shorten the process chain, as shown in Table I. Attempts have been made to remove the stages of pelletizing and sintering by agglomeration–prereluction, direct reduction, briquetting, lumpy-ore upgrading, and the plasma technique. Some attempts failed at the laboratory stage, some at the pilot-plant stage, and still others not until after expensive industrial trials.

These aspects are also becoming increasingly important for other producers because high-grade and hard, lumpy ore is becoming less readily available and more expensive. The production of ferrochromium in a simple open submerged-arc furnace is profitable only in a few works.

Targets

From the beginning, the target has been total profitability, starting from Kemi chromite and ending with ferrochromium.

The reduction of chromite always needs a certain theoretical amount of reductant and thermal energy. As by-products of ferrochromium, slag and gas are always formed: these have a certain enthalpy, and in addition the gas has a combustion energy.

The development of a continuous reduction process in which the input of primary energy, and the material and heat losses, are as low as possible, remains our target. In addition, the utilization of unavoidable by-products as secondary energy has to be maximized.

However, the basis for all the developmental work is continuity of the hot part of the process chain. If this cannot be achieved, no single innovation can rescue the economics of the process.

When continuity has been achieved, the size of the reduction unit has to be optimized. Energy usage and productivity improve when the scale of the process increases; therefore, the development of a continuous reduction unit on as

TABLE I
DEVELOPMENT STAGES OF OUTOKUMPU'S FERROCHROMIUM PROCESS

	Pretreatment Process	Laboratory-scale tests	Pilot-scale tests	Industrial scale-tests	Industrial scale-production	Cr in FeCr %	Size of submerged-arc furnace MVA
1	Selective iron reduction in rotary kiln, iron separation by H ₂ SO ₄ or by gravimetric methods, pelletizing and sintering in shaft furnace, preheating in rotary kiln	1966 – 70	1966 – 70		1968 – 70	60	15
2	Pelletizing and sintering in shaft furnace, preheating in rotary kiln	1970 – 85			1970 – 73 1975 – 86	52	24 35
3	Prereduction and agglomeration in rotary kiln	1971 – 75 1978 – 84	1983 semi-industrial	1970 – 72	1973 – 75	52	24
4	Direct reduction in rotary kiln	1984 – 85					
5	Briquetting	1981 – 83	1981 – 83	1981 – 83			
6	Upgrading of lumpy ore	1981...					
7	Upgraded lumpy ore and pellets 70/30, pelletizing and sintering in shaft furnace, preheating in shaft kiln	1984 – 88	1984 – 87		1985 – 90 1986 – 90	52 – 55	75 35
8	Smelting by non-transferred plasma arc		1988				
9	Upgraded lumpy ore and pellets 30 – 50/70 – 50, pelletizing and sintering in steel-belt furnace, preheating in shaft kiln	1988 ...	1988...		1990...	52 – 55	35 and 75

large a scale as possible is a priority. When this basic metallurgical and equipment technology works, the fine tuning of the details of the process chain can be started.

Pretreatment of Kemi Chromite

Owing to its low chromium oxide content and low melting point, Kemi ore could not be used for ferrochromium production without being concentrated. It was also found that most of the ore had to be finely ground for concentration. After extensive studies, pelletizing and sintering of the fine concentrate and smelting with a preheated charge in a closed furnace were chosen as the basic philosophy for ferrochromium production.

Analyses of the Kemi concentrate, lumpy ore, and upgraded lumpy ore are presented in Table II.

TABLE II
CHEMICAL ANALYSES OF KEMI CHROMITES CURRENTLY USED
(IN PERCENTAGES)

Component	Lumpy ore	Upgraded lumpy ore	Concentrate
Cr ₂ O ₃	25,0	34,6	42,4
Fe (total)	10,4	13,6	18,8
Fe ²⁺	8,3	10,9	13,9
SiO ₂	20,5	11,8	4,2
Al ₂ O ₃	8,8	11,3	12,9
MgO	20,5	16,4	11,3
CaO	2,0	1,3	0,5
CO ₂ (carbonate)	4,5	3,3	1,8
H ₂ O (hydroxide)	4,0	3,3	1,0

Selective Reduction of Iron from Chromite

The purpose of chromite processing at the end of the 1960's and in the beginning of the 1970's was to metallurgically increase the Cr/Fe ratio from the original 1,5 to 3, thus satisfying the demand for a minimum 60 per cent chromium content in ferrochromium by the steel industry. The aim

was to reduce and nodulize iron selectively in a rotary kiln, and then to separate metallic iron by sulphuric acid extraction or by gravity concentration. The metallurgically enriched chromite was wet-ground, pelletized, and sintered in a shaft furnace.

Laboratory and pilot-plant investigations

The investigations on both laboratory and pilot-plant scale concentrated on increasing the grain size of the metallic nodules. The temperature relationships and the effect of additives such as sulphur and phosphorus compounds were investigated. The pilot-scale investigation was carried out with a rotary kiln.

In Figure 1, the reduction of chromium is presented in relation to the reduction of iron under laboratory conditions. It can be seen that the selective reduction of iron at high levels is difficult because of the simultaneous reduction of chromium, which increases the losses of soluble chromium.

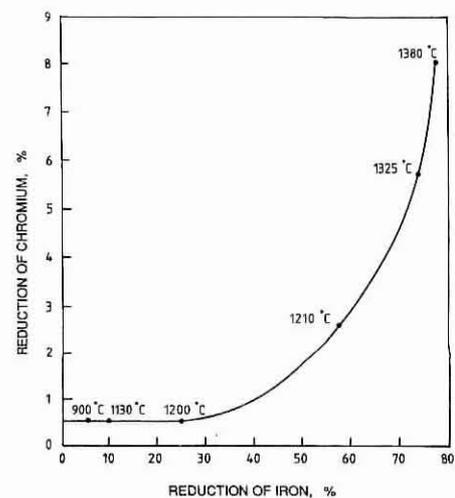


FIGURE 1. Reduction of chromium and iron at different temperatures

Industrial-scale production

This process was operated on an industrial scale at the Tornio plant from 1968 to 1970. Reduction took place in a 55 m rotary kiln with an inside diameter of 2,3 m at a temperature of 1450 °C with heavy oil as the fuel. Both fine concentrate with coke and composite pellets with 5 to 15 per cent coke were used. The pellet charge was preheated in the 42 m rotary kiln to between 800 and 1000 °C, with CO gas from smelting as the fuel, before being smelted in a closed 15 MVA submerged-arc furnace.

Some daily results are shown in Table III, for which the residual carbon and metallization rates of chromium and iron were determined according to the formula

$$\text{Metallization rate (\%)} = \text{Me soluble} / \text{Me total} \times 100. \quad [1]$$

TABLE III
SOME DAILY ANALYSES OF THE KILN PRODUCT FROM THE
PLANT TESTS

Day	Metallization, %		Residual carbon %
	Fe	Cr	
1	73	12	1,6
2	74	16	1,2
3	74	13	0,8
4	47	3	0,2
5	64	8	1,0
6	72	10	1,5
7—	59	4	0,5
24	75	16	1,3
Mean	69	8	1,0

From our experience, there must be about 1,5 per cent free carbon in the product if overheating of the bed and ring formation are to be avoided. The Boudouard and water-gas reactions control the temperature.

The average analysis of the metallic nodules in the product was chromium 6 to 25 per cent, sulphur 1 per cent, and carbon 1 per cent.

Difficulties of the process

The recovery of chromium in the enriched sintered pellets on the industrial scale was 80 to 90 per cent, which was too low. It was difficult to determine the metallization degree owing to difficulties in dissolving the carbides in dilute sulphuric acid. There were large variations in the reduction rates of iron and chromium, and other negative features included ring formation in the rotary kiln and a large consumption of coke. Many general technical problems also occurred, e.g. the burning of additional air tubes. This process chain was very complicated, difficult to control, and costly.

The research work and production were continued until the AOD process for stainless-steel production made the route unnecessary.

Prereduction and Agglomeration of Chromite Concentrate

After the selective reduction of iron, the main focus of the investigation moved to the development of the pre-reduc-

tion-agglomeration process, which was in principle a simplified version of the earlier process. In this process, the aim was to produce prereduced agglomerates from concentrate at high temperatures in a rotary kiln. The target was generally to obtain more than 80 per cent iron and 10 per cent chromium in a metallic form, and hot nodules with a grain size of 5 to 20 mm. The process was to have replaced the existing pelletizing-sintering process and separate pre-heating kiln. It would thus have achieved notable savings in the consumption of electrical energy in the smelting furnace, according to theoretical calculations.

The investigations and studies were aimed at a quick introduction of the prereduction-agglomeration process. Process research work was carried out on an industrial scale in a rotary kiln as a separate process. The production process operated from 1973 to 1975, when the rotary kiln was connected, via the feeding ring, direct to the smelting furnace. During that time, the charge also contained sintered pellets, and the pellet process continued normally.

The details of the reduction and agglomeration process and the smelting of the prereduced product were studied in laboratory and pilot-scale tests. During the development of the process, sulphur reduction was also investigated because, according to the calculations, the sulphur level was too high. A method for sulphur reduction was developed and patented, and sulphur was reduced in a ladle on a full scale.

At the end of the 1970's, different process alternatives were studied, and the process still seemed promising. New process studies and laboratory investigations were therefore started, as well as the design of pilot-scale test equipment. This phase ended in 1983 with a large (semi-industrial) pilot-plant test run in a rotary kiln/electric-furnace system.

Industrial-scale investigation

The process was investigated very carefully, firstly as a separate process with the existing rotary kiln arrangement. The following aspects were investigated:

- retention time versus rotation speed of the kiln
- temperature profile along the kiln
- degree of reduction (Cr, Fe) and the profile of gas components along the kiln length
- consumption of coke by different reactions.

Figures 2 and 3 present some specific values. The curves in Figure 2 show that it was very difficult to control the temperature profile, and almost impossible to measure it continuously. It was therefore also difficult to control the

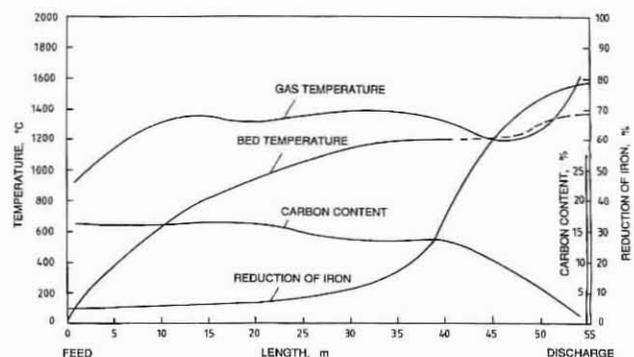


FIGURE 2. Profiles of gas and bed temperatures, carbon content, and reduction of iron along the length of the kiln

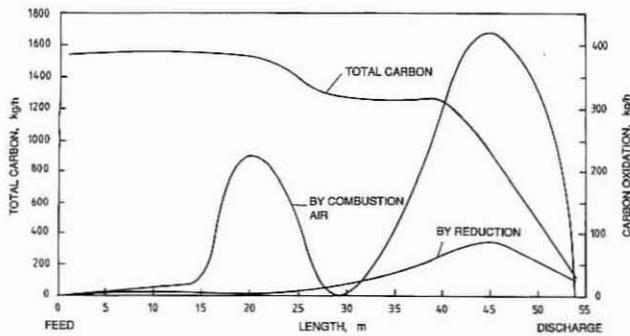


FIGURE 3. Profiles of total carbon and consumption of carbon by oxidation and reduction along the length of the kiln

carbon content along the kiln.

The consumption of carbon by different reactions was difficult to quantify, and thus the product quality varied greatly.

The following observations were made about the segregation of carbon,

- Segregation was very marked, particularly in the cold end of the kiln, when the concentrate and coke were fed separately. The coke floated on the bed of concentrate due to its different bulk density.
- Segregation was observed along the kiln, as well as in the radial direction, and varied according to the thickness of the bed.

Figure 4 gives the measured values of carbon content 15 m from the feed end. According to the test results, the segregation of carbon is very pronounced, and therefore has

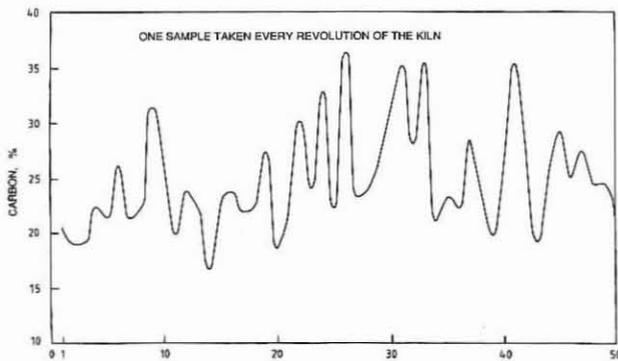


FIGURE 4. Carbon content sampled 15 m from the feed end of the rotary kiln

great effect on the product quality.

In Figure 5, the sinter profile is shown after a test run of some weeks. The sintering inside the kiln was not regular and the profile changed, which affected the rate of material and heat transfer, as well as increased the segregation effect and variations in product quality and output.

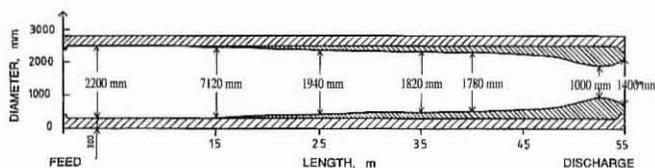


FIGURE 5. The sinter profile in the test kiln

Industrial-scale production

On the basis of the test results and operational experience, the process flowsheet was changed and the equipment improved. A preheating cyclone was built to preheat the concentrate to 900 °C with the gas from the rotary kiln. The capacity of the kiln was thus increased, and the temperature profile was more controllable. The heating rate was reduced, and the degree of automation was also improved.

However, the same type of difficulties as before were experienced in the start-up of the kiln. The main problems were uncontrolled sintering in the kiln when the temperature measurements of the bed along the kiln were not manageable, and variations in product quality. Because of sintering problems, the amount of kiln product also varied considerably. Accurate feeding of coke and fluxes appeared impossible, and this naturally caused major problems in the smelting stage.

Start-up of the process was attempted several times, and some equipment repairs and modifications were made between the start-ups. However, a satisfactory continuous operation was never achieved. The process was therefore abandoned, and the kiln equipment was used for the preheating of the pellet charge. Nevertheless, it was decided to continue the development of the prereluction process on a pilot scale.

Smelting tests of preheated, prerelucted charge on a pilot scale

The aim of these investigations was to study the behaviour of prerelucted and agglomerated chromite in smelting when the charge was preheated in a rotary kiln to 1000 °C. The factors affecting the sulphur level in ferrochromium, e.g. composition of the slag, were also investigated.

Reduced and preheated agglomerates, made in the Tornio Works, were successfully smelted in a 500 kVA electric-arc furnace. The furnace operation was even, but the controlling effect of the grain size of chromite on the operation was significant, i.e. the large amount of fines caused problems.

In the tests, the recovery of chromium was very high, peaking at 93 per cent, and the consumption of electrical energy in the smelting itself was as low as 1700 kWh per tonne of ferrochromium.

All these test results were very promising concerning the smelting, and they formed the basis for economic and technical studies on an industrial scale.

Batch tests on pilot-plant scale

The purpose of these investigations was to improve our knowledge of the prereluction-agglomeration process, and to clarify primarily the effect of temperature and additives on agglomeration and prereluction.

The tests were carried out in a combustion-chamber type of furnace with a length of 2 m and an inside diameter of 1 m. Altogether, 24 batch tests were conducted with different fluxes. The grain size of the coke used in the tests was minus 3 mm, and the concentrate was approximately 15 per cent minus 200 mesh.

The concentrate started to agglomerate at 1250 to 1300 °C with additives, and without additives at 1300 to 1400 °C.

The surface temperatures of the bed were very high, with oxygen enrichment over 1500 °C, and the reduced metal in the concentrate started to melt and separate as a distinct

phase. During one test, a flow of liquid metal was noticed in the furnace.

The reduction of iron in the products varied between 55 and 77 per cent, and that of chromium between 5 and 17 per cent. The greatest degree of reduction was achieved when both fine limestone and quartzite were added, when the sintering could also be best avoided. It was very difficult to control the grain size of agglomerates. Quality, grain size, and the amount of additives had a great effect on the results.

These test results from batches in the rotary kiln were not so promising, and we again focused our interest on the real basis of the process.

Continuous operation on semi-industrial scale

The prereduction-agglomeration process was investigated again on a laboratory scale for 5 years and, during the same period, many feasibility studies were conducted on an industrial scale. According to these studies, the process seemed to be very promising and profitable, mainly because it is in principle very simple and cheaper fossil energy can be used in the rotary kiln, instead of expensive electrical energy. All the test results supported the earlier observations that high chromium recoveries can be obtained in smelting.

Because of these facts, a decision was made to carry out long trials on a semi-industrial scale.

The concentrate feed to the kiln took 1300 hours, and the feed to the electric furnace took 380 hours. The test equipment consisted of an 11 m rotary kiln with an inside diameter of 1,4 m operated in the countercurrent method. The kiln product was fed directly through the feeding ring to a 2 MVA closed electric furnace. Coal powder, and a mixture of coal powder and butane with oxygen-enriched air, were used to fuel the rotary kiln.

The grain size of the kiln product was approximately in the desired range when either fine quartzite or quartzite and dolomite were used as fluxes. When only dolomite was used as a fluxing agent, a reduction degree of 70 to 75 per cent was achieved for iron and 5 to 10 per cent for chromium, but the grain size of the product was too small. When lumpy ore was used as a part of the concentrate feed, the reduction rate was decreased. In these conditions, the replacement of coke by coal did not improve the reduction. The product temperature was in the range 1350 to 1450 °C.

Sintering started at a temperature of about 1200 °C, when the chromite particles started to stick to one another by a small amount of melting silicate, and also formed a layer of porous metallic sinter on the walls of the kiln. At times, 3 to 30 per cent of the different components was left on the sinter in the kiln, and at other times over 50 per cent.

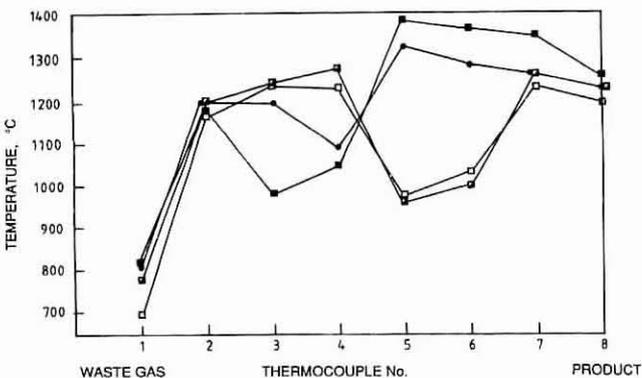


FIGURE 6. Inside temperatures of the lining along the kiln during four days

Figure 6 shows the temperature profile along the kiln during four days. Continuous measurement showed that it was impossible to control the temperature profile of the kiln because of the sintering of the feed on the lining.

In Figure 7, the prereduction rates and carbon content of the product are illustrated. These curves show that there were great variations in the carbon content and in the reduction of iron and chromium, which indicates the fluctuating conditions in the smelting operation.

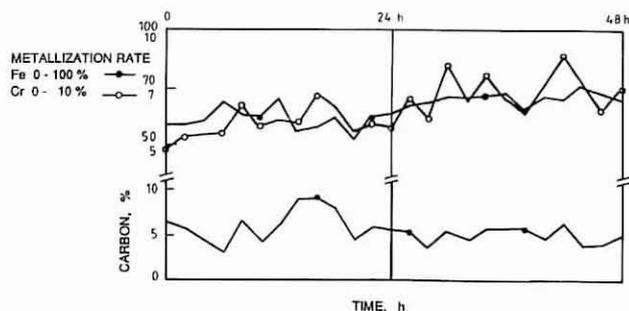


FIGURE 7. Metallization rate of iron and chromium, and carbon content in the kiln product

Sinter formation on the lining and additional air tubes could be avoided only occasionally, and this was a major problem in the trials. Figure 8 shows the strong sintering effect and sintering of dust on the secondary air tubes.

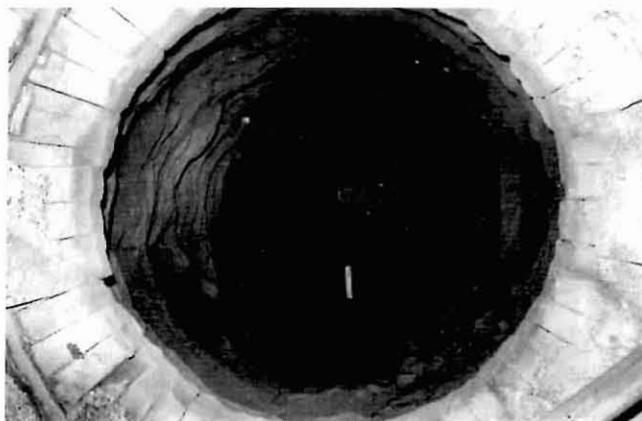


FIGURE 8. Interior of the rotary kiln after two weeks' trial

The sulphur content of the ferrochromium produced from the agglomerated charge was much higher than that of the ferrochromium produced from the pellet charge, partly as a result of the greater carbon consumption on the pilot scale.

Again, during smelting the chromium recovery was very high, up to 95 per cent, but the consumption of electrical energy was clearly higher than had been calculated owing to problems with the kiln operation.

Because of these negative results, the investigation of the prereduction-agglomeration process was halted, but the prereduction results can, of course, be utilized to clarify the reducibility of chromite.

Direct reduction of chromites on a laboratory scale

The aim of this process was to replace the sintering and smelting process with the total reduction of chromite in a rotary kiln. Thus, cheaper fossil fuels could be used as an energy source instead of expensive electrical energy.

The test equipment was a plasma-heated rotary kiln. The effect of different kinds of fluxing agents on the reduction was investigated.

The reduction of fine concentrate would have been carried out on a production scale with solid carbon at high temperature in a rotary kiln by a countercurrent method, followed by cooling in a rotary drum with water spraying. Oil or coal dust would have been used as fuel, with oxygen enrichment. The target was to produce small ferrochromium globules (of a few millimetres at most) suitable for further use. The globules would have been separated from the slag by crushing and enrichment methods.

Figure 9 shows the sintering effect of different batches. The greater the compressive strength of the pressed sample after the test, the easier the material melted.

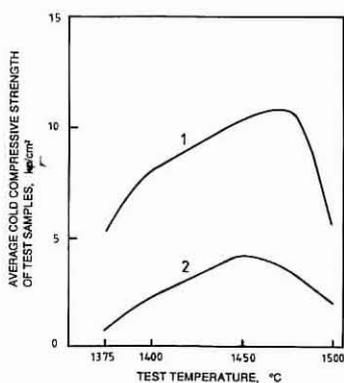


FIGURE 9. Cold compressive strengths of pressed samples as a function of temperature

1. Concentrate + coke
2. Concentrate + coke + MgO powder

Figure 10 shows the mass losses in direct reduction. These data indicate the different reduction rates of iron and chromium.

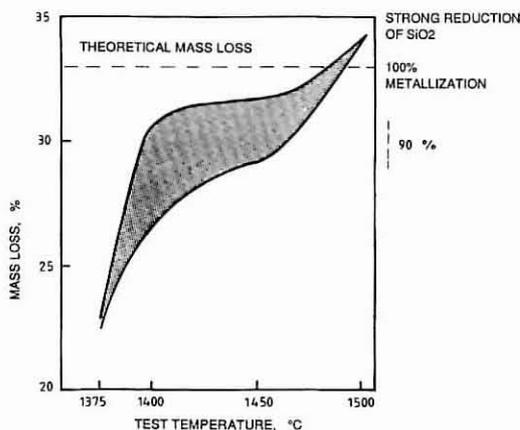


FIGURE 10. Mass losses of different batch types as a function of temperature

The following results were obtained in the investigations.

- Over 90 per cent metallization was achieved with iron and chromium.
- The best metallization and metal separation were achieved with the mixture of magnesite and a small amount of quartzite in the temperature range 1475 to 1500 °C. About 53 per cent of the chromium from the feed was in the plus 1,68 mm fraction, 27 per cent occurred as visible metal droplets, and 10 to 11 per cent as very fine droplets in the matrix.

- Chemical analysis showed that the metallic droplets contained 0,5 to 5,0 per cent silicon and 6,5 to 8,7 per cent carbon.
- The process was very sensitive to temperature control and segregation of the additives.
- Local overheating and melting of the batch occurred easily, and this led to the formation of a sinter ring.

It was concluded that the rotary-kiln process cannot be applied on a production scale with Kemi chromite, which contains a lot of silicates of low melting point.

Briquetting and Cold Bonding of Chromites

The briquetting process was intended to replace the pelletizing and sintering process, and thus to achieve considerable savings in operating costs.

Briquetting was investigated partly simultaneously on a laboratory scale, a pilot-plant scale, and an industrial scale in Tornio ferrochromium plant. Several organic and inorganic materials were used as bonding agents.

Measurements of the hot compressive strength of the briquettes (Figure 11) showed that the critical temperature ranges were 300 to 400 °C and 700 to 800 °C, when the strength falls. In the lower temperature range, there were some plastic briquettes and, in the higher range, the volatile matter decomposed according to thermoanalytical principles. The briquettes strengthened again a little at about 1000 °C.

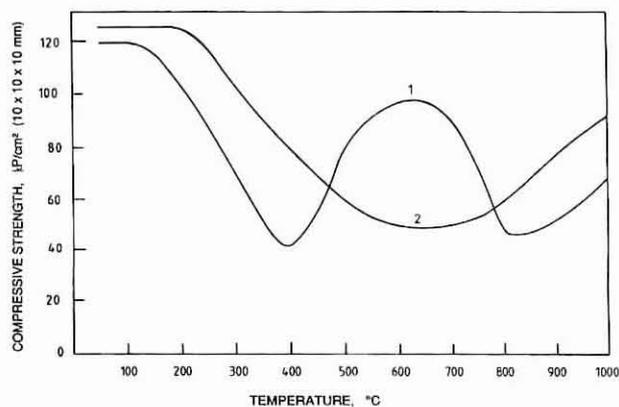


FIGURE 11. Hot-compressive strength of molasses-bonded briquettes as a function of temperature

1. Heating to the fixed temperature in 120 minutes
2. Heating to the fixed temperature in 50 minutes

Observation of smelting slags on the industrial scale showed that, when briquettes were used, a lot of primary chromite remained in the slag. The trials were halted because of the decreased chromium recovery in smelting and the unstable electric-furnace operation.

The production of hardened pellets in an autoclave by the well-known Swedish COBO-process was studied. The tests and the pre-feasibility study indicated, when the whole production chain for ferrochromium was taken into consideration, that no economic benefit would be achieved from the use of this process in place of the pelletizing and sintering process.

Pellets and briquettes based on Portland cement were also investigated, but these disintegrated very easily when heated. The studies were therefore discontinued.

Plasma Smelting

The aim of these studies was to clarify the application of the d.c. plasma principle to the production of ferrochromium and to increase our knowledge about plasma phenomena. The metallurgical advantages of the plasma method over the submerged-arc production of ferrochromium, are widely known from written reports, as far as the process works as described in the literature.

Outokumpu had investigated the smelting of chromite in a non-transferred d.c. plasma reactor on a pilot-plant scale. These investigations were performed in co-operation with the Helsinki University of Technology. A 250 kW pilot burner was used as the plasma burner, with nitrogen as the plasma gas. The test reactor consisted of a short vertical reaction shaft. The burner was located on the top of the shaft.

Solid reaction products dropped to the so-called settler part of the furnace, and the gases were conveyed to a cleaning system. The feed was injected into the flame of the burner at a rate of about 20 kg/h for about 2 hours. The feed mixture consisted of Kemi chromite and coke, with lime and quartzite as fluxes.

In the tests, the influence of reductant, basicity of the slag, and melt temperature on the solubility of Cr_2O_3 in the slag was investigated.

The Cr/Fe ratios in the metal phase were high, even higher than in the feed, which shows that iron was reduced and vaporized selectively in the plasma flame. The degree of vaporization of the impurity components, sulphur and phosphorus, in the hot gas flame of the plasma burner was very high.

So called in-flight reduction was not examined separately, but notable amounts of metallic iron and metallic chromium were observed in the dust. This shows that part of the reduction occurred in-flight.

Together with these non-transferred d.c. plasma tests, the application of the d.c. arc-furnace principle to the smelting of chromite was investigated. These investigations are still in progress, and no results are yet available.

Outokumpu is not at present ready to implement a plasma-based process for the industrial-scale production of ferrochromium, because there are still too many technical difficulties and the size of the equipment does not meet the financial preconditions for production. In particular, preheating and prereluction of the feed and utilization of the reduction gas need much investigation and development.

Comparison of Pretreatment Methods

The following section summarizes the results of the different investigations into the heating of pellets, lumpy ore, and briquettes under reducing conditions on laboratory, pilot-plant, and industrial scales when ferrochromium is produced in a submerged electric-arc furnace. Outokumpu considers that the smelting of chromite fines directly in a submerged-arc furnace is not feasible.

Experience has shown that the chromite raw material must be durable during heating and must withstand mechanical wear without disintegrating. Dust losses lower the chromium recovery, and chromite fines melt and dissolve easily into the slag, where they are difficult to reduce. In addition, the chromite itself and the feed mixture should have high melting points, so that the reduction proceeds mostly in the solid state. On the other hand, the molten

phases in the upper part of the bed greatly increase the electrical conductivity of the charge, and thus the smelting process is disturbed.

Lumpy ore and briquettes

Generally, most lumpy ores are hard and withstand mechanical wear at room temperature, but their character often changes during heating in the upper part of the bed inside an electric furnace, as well as in preheating equipment.

When lumpy ore is preheated, the volatile matter decomposes, and cracks are formed between the chromite grains and the gangue. The structure breaks, forming dust and fines.

The behaviour of briquettes is similar to that of lumpy ore. Briquettes include more fines and could therefore be less economical to use than lumpy ore, depending on the quality of the ore or briquettes.

Sintered pellets

Although pelletizing-sintering extends the ferrochromium production process and increases investment costs, the increased costs will be quickly offset by reduced smelting costs.

In Outokumpu's experience, the use of sintered pellets has the following advantages.

- The quality of sintered pellets is more homogeneous because of the ground structure.
- As iron in the pellets is oxidized to Fe^{3+} , its reduction starts more easily than that of Fe^{2+} in the raw chromite. Iron also occurs in the pellets as precipitates and on the surface of the chromite grains. The structure of the chromite lattice is therefore totally different from that of the original material.
- Ground chromite in sintered pellets has a large specific surface area owing to very small pores in the structure, and thus the reduction rate is highly increased.
- The porous structure of the pellets more easily prevents the melt formed in the upper part of the bed from emerging at the surface of the pellets, and therefore the electrical conductivity of the smelting charge does not increase as easily as that of ores and briquettes.
- The pellets are more resistant to heat and mechanical wear.
- The flow of the reduction gas through the burden is smooth.
- The volatile matter (hydroxide, carbonates) decomposes during the sintering. The consumption of electrical energy and coke is therefore smaller, and the danger of explosion is eliminated.

All these positive features of sintered pellets result in high chromium recovery, high operational efficiency, and safe operating conditions, and large production units can be used.

Outokumpu Ferrochromium Process Today

Between 1985 and 1990, the Outokumpu ferrochromium process at Tornio underwent the biggest changes in its history.

- The production capacity was tripled from 60 to 210 kt per year.
- The rotary preheating kiln was replaced with a stationary shaft-type preheater.
- The shaft-furnace sintering of pellets was replaced with

steel-belt sintering, and the capacity of the sintering plant was doubled from 150 to 300 kt per year.

- Upgraded lumpy ore is also used as a raw material with the sintered pellets.
- The whole process chain is now controlled by a computer-based system.

In 1985 a new, larger production line, rated at 75 MVA, became operational. A completely new stationary preheater was developed for this line. In 1986 the 35 MVA line was renewed and equipped with a similar shaft-type preheater.

At the end of 1989, the new steel-belt sintering plant was started. The concept was originally developed by the Swedish company LKAB for the sintering of iron-ore pellets. The energy consumption in pellet production is now 50 per cent lower than with the old shaft-furnace sintering. Also, the consistency of pellet quality is better, and the throughput is higher. In practice, it is possible to build a steel-belt sintering plant with a capacity of over 500 kt per year, while the practical capacity limit for one shaft-sintering unit is about 200 kt per year.

The operating targets for the coming years for the 75 MVA production unit are

- to increase preheating by the use of CO gas
- to increase the active power of the submerged-arc furnace
- to further increase the operational time from its present value of about 97 per cent in one calendar year
- to utilize the CO gas completely.

A higher chromium content in chromite increases the melting point and homogenizes its chemical composition. This increases the reducibility and cuts the overall energy consumption of the production line. For this reason, the chromium oxide content of chromite is to be increased by the development of concentrating methods.

Labour productivity at the Tornio plant is now 1,6 man-hours per tonne of ferrochromium. Our target for the future is 1,0 man-hour per tonne.

The current production line is shown schematically in Figure 12.

Conclusions

In the production of ferrochromium, the most important stage is the reduction of chromite. The purpose of all the preceding unit operations is to secure the reliable, continuous operation of the reduction stage. If consistency of a selected reduction method cannot be achieved, no low-cost raw material, reductant, or energy can make the plant profitable. The reduction process is a typical high-temperature process in which the most economical unit size is the largest possible in practice. When the reliability and size are maximized, the basis for the development of an industrial process is found. In that work, the miners, metallurgists, and equipment designers have only one target: a profitable operation.

For the utilization of Kemi chromite, Outokumpu has carried out intensive research-and-development work for more than 20 years. In our opinion, no competitive alternative for a submerged-arc furnace has been found that is capable of producing over 100 kt of ferrochromium per year.

It was found that the prereluction-smelting of fine concentrate worked well on smaller scales. The promising results achieved in pilot-scale tests were, however, not borne out on an industrial scale. Running of the big rotary-kiln process with a continuously controlled degree of prereluction appeared to be an overwhelming task.

Outokumpu is currently attempting to increase its competitiveness by developing the metallurgical and equipment aspects of the process based on the use of sintered pellets and upgraded lumpy ore as the charge. We already have in operation a structurally simple, large continuous smelting unit equipped with preheating. The power has been increased fourfold, and the production and labour productivity fivefold, compared with the original.

For the future, we are considering a process in which fine ore is upgraded to an optimum extent, and can then be prerelucted in a controlled way so that the prereluction and composition remain consistent. The final reduction will be made by electrical power or fossil fuel. The enthalpy and combustion energy of CO gas from the furnace will be used in the preheating or prereluction process.

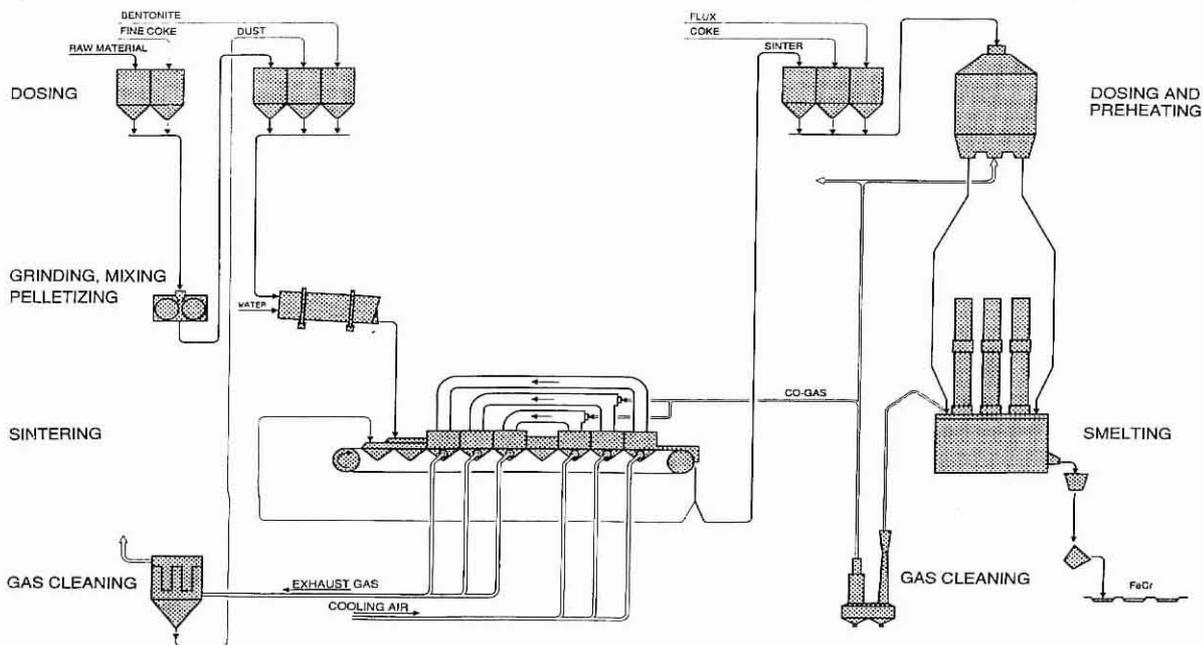


FIGURE 12. Ferrochromium process at Outokumpu Chrome Oy, 1991