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Recent developments in the ferro-alloy field in South Africa

by

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Synopsis

The ferro-alloy industry in South Africa has witnessed a spectacular growth since the Seventh Commonwealth Mining and Metallurgical Congress, in 1961.

The reserves of manganese ore, chromium ore, and carbonaceous reducing agents are discussed briefly, and the growth of the industry is traced by use of a record of furnace installations. Technological developments in the industry include an increase in furnace size and power rating, progress in agglomeration techniques, and computer-aided control. The development of a technique for the decarburization of high-carbon ferrochromium was a major factor in the growth of the country's ferrochromium industry.

Research of a more fundamental nature, which was carried out at universities, played a key role in providing an improved understanding of how South African raw materials behave both metallurgically and electrically in smelting furnaces.

Current research work and likely future developments in the industry are discussed. The most interesting prospects include even more-advanced computer-based control and optimization of large electric-smelting furnaces, new furnace designs based on the plasma arc, and the use of fluidized-bed reactors for the pretreatment of ore fines prior to their agglomeration, or preferably prior to their direct charging to plasma furnaces.

Good collaboration between industry and research-and-development organizations, as well as an open-minded approach to new challenges, has been largely responsible for the successes reaped by the ferro-alloy industry in the face of great foreign competition.

It will almost certainly be in the field of new stainless-steel alloys that future growth will occur, and South Africa can look forward to another twenty-one years of growth and new developments.

Introduction

South Africa possesses the world's largest known reserves of manganese and chromium ores. Owing to its fast-developing infrastructure, the country is in a position to extract these ores at a lower cost than most developed nations and, because of careful long-term planning, has remained largely unaffected by the oil-price increases in terms of the cost of primary energy (some 80 per cent of the Republic's power is generated by coal-based thermal-power stations).

It is therefore not surprising that the ferro-alloy industry in South Africa has grown by leaps and bounds during the past twenty-one years, realizing an annual growth rate of almost 12 per cent. In addition, research-and-development activities have grown, and are continuing to grow.

Ore Reserves

Providence has been particularly generous in endowing South Africa with its wealth of mineral resources, but at the same time has played a practical joke on its residents by either creating vast reserves of low-grade material or else providing high-grade resources that are refractory and difficult to extract from the earth[1]. As shown in Fig. 1, South Africa features prominently in world mineral reserves[2]. In fact, South Africa is ranked first in the entire world for the first seven items, four of which are essential to iron- and steel-making.

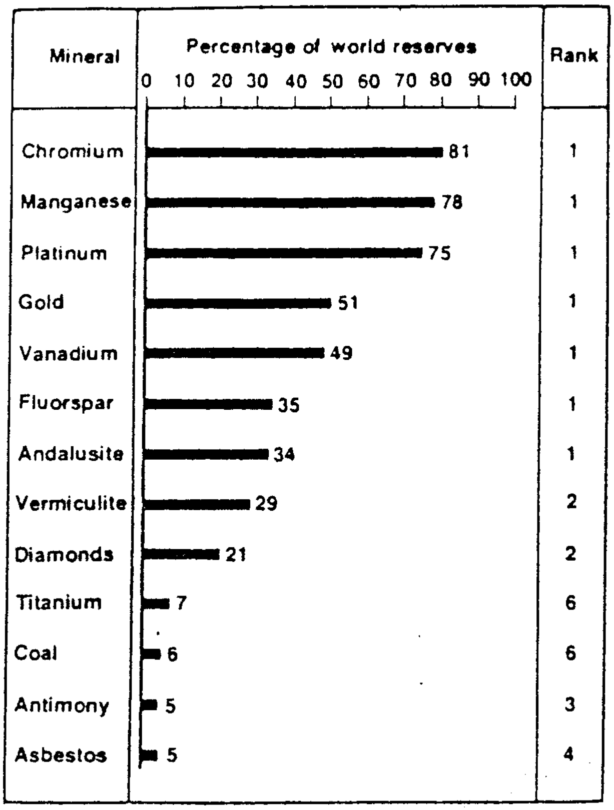

Fig. 1—The role of South Africa in world mineral reserves, 1978[2]

Reserves of Manganese ore

Excluding reserves of deep-sea nodules, which still have questionable economic viability, the total reserves of manganese ore in the world have been estimated[3] at some 15 000 Mt, as indicated in Table I. Of this total, South Africa and the U.S.S.R. together account for 90 per cent, with South Africa contributing some 12 000 Mt and the U.S.S.R. an estimated 1200 Mt.

The South African reserves are of a high grade, with an estimated minimum manganese content of 28 per cent. The estimate does not include any possible lower-grade deposits in the area, which has not yet been adequately mapped. These high-grade metallurgical ores occur almost exclusively in two fields in the north-western Cape: the Postmasburg field and the Kalahari field.

TABLE I

World reserves of manganese ore[3]

Country	Reserves Mt	%
South Africa	12 139	78,9
U.S.S.R.	1 224	8,0
Australia	874	5,7
Gabon	517	3,4
Mexico	215	1,4
Brazil	161	1,0
U.S.A.	67	0,4
India	36	0,2
China	31	0,2
Ghana	31	0,2
Upper Volta	13	0,1
Zaïre	4	—
Balance	73	0,5
World total	15 385	

At present, three companies are actively involved in mining these fields, and in 1980 the combined output was some 6 Mt, which approximates one-quarter of the world's production of managanese ore.

Reserves of Chromium Ore

Present-day estimates[4] of the world's reserves of chromium ores, as shown in Table II, vary from a probable figure of just below 4000 Mt to a potential 5400 Mt. Of this total, South Africa has a probable 3000 Mt and a potential of 4000 Mt.

TABLE II

World reserves of chromium ore[4]

	Certain and probable		Potential	
	Mt	%	Mt	%
North America				
Canada	—	—	8,0	8,0
U.S.A.	—	—	8,0	0,15
Total	—	—	16,0	0,3
South America				
Brazil	7,0	0,2	11,0	0,2
Colombia	0,1	—	—	—
Cuba	1,0	—	5,0	0,1
Total	8,1	0,2	16,0	0,3
Africa				
Madagascar	11,0	0,3	50,0	0,9
Sierra Leone	—	—	1,5	—
South Africa	3 096,8	80,7	4 000,0	74,0
Sudan	0,5	—	—	—
Togo	—	—	0,5	—
Zimbabwe	560,0	14,6	1 000,0	18,5
Total	3 668,3	95,6	5 052,0	93,4
Western Europe				
Denmark/Greenland	—	—	2,5	—
Finland	33,0	0,9	—	—
Greece	1,0	—	25,0	0,5
Yugoslavia	0,5	—	—	—
Total	34,5	0,9	27,5	0,5
Asia				
Afghanistan	—	—	0,5	—
Cyprus	0,2	—	—	—
India	14,0	0,4	26,0	0,5
Iran	5,0	0,1	40,0	0,7
Japan	0,5	—	1,0	—
North Vietnam	0,5	—	—	—
Pakistan	2,0	—	2,0	—
Philippines	10,0	0,3	9,0	0,2
Turkey	10,0	0,3	50,0	0,9
Total	42,2	1,1	128,5	2,4
Rest of world				
Albania	6,5	0,2	15,0	0,3
Australia	—	—	2,0	—
U.S.S.R.	80,0	2,1	150,0	2,8
Total	86,5	2,3	167,0	3,1
Total world reserves	3 839,6	100,0	5 407,0	100,0

TABLE III

History of South African ferro-alloys (excluding present-day carbide furnaces)

Year	Company	Alloy	Scale of operation	Total installed MVA
1928	Rand Carbide	CaC_2	1 × 2,5 MVA 3 × 6 MVA	20,5
1938	Samancor (Newcastle)	FeMn	Blast furnace	20,5
1942	Samancor (Vereeniging)	FeMn, FeCr, FeSi	2 × 3 MVA	26,5
1946	Samancor (Newcastle)	FeMn	Blast furnace	26,5
1951	Samancor (Metalloys)	FeMn, FeCr, FeSi	2 × 12 MVA	50,5
1952	Rand Carbide	CaC_2	1 × 25 MVA (replacing 14,5 MVA)	61,0
1958	Samancor (Metalloys)	FeMn	Additional 20 MVA (replacing 2 × 3 MVA)	75,0
1958	Samancor (Ferrometals)	FeSi, FeCr	2 × 7,5 MVA	90,0
1960	Samancor (Ferrometals)	FeSi, FeCr	1 × 15 MVA	105,0
1960	Feralloys (Cato Ridge)	FeMn	2 × 9 MVA	123,0
7th Commonwealth Mining and Metallurgical Congress				
1963	MSA (RMB)	FeCr	1 × 16 MVA	139,0
1963	MSA (Palmiet Chrome)	FeCr, SiCr	1 × 9 MVA	148,0
1964	MSA (RMB)	FeCr	5 × 7,5 MVA	185,5
1964	Feralloys (Cato Ridge)	FeMn	2 × 9 MVA	203,5
1964	Transalloys	FeCr, SiCr	2 × 4 MVA 2 × 15 MVA	241,5
1965	MSA (RMB)	FeCr	1 × 7,5 MVA	249,0
1965	Rand Carbide	FeSi	1 × 16 MVA	265,0
1966	MSA (Palmiet Chrome)	FeCr	1 × 16 MVA	281,0
National Institute for Metallurgy founded				
1967	MSA (RMB)	FeCr	1 × 7,5 MVA	288,5
Pyrometallurgy Research Group established 1969				
1970	MSA (Palmiet Chrome)	FeCr	1 × 9 MVA	297,5
1971	Feralloys (Machadodorp)	SiCr	1 × 24 MVA 1 × 12 MVA	333,5
1972	Feralloys (Machadodorp)	SiCr	1 × 24 MVA	357,5
1972	Rand Carbide	FeSi	1 × 46,5 MVA	404,0
1973	Samancor (Ferrometals)	FeSi, FeCr	2 × 48 MVA	500,0
1973	Samancor (Silicon Smelters)	Si Metal	3 × 25 MVA	575,0
1974	Samancor (Metalloys)	FeMn	2 × 48 MVA	671,0
1974	Feralloys (Machadodorp)	FeCr	1 × 12 MVA	683,0
1975	Samancor (Ferrometals)	FeCr	1 × 48 MVA	731,0
1976	Feralloys (Cato Ridge)	FeMn	1 × 24 MVA	755,0
1976	Tubatse	FeCr	1 × 30 MVA	785,0
1976	Feralloys (Machadodorp)	FeCr	1 × 24 MVA	809,0
1977	Tubatse	FeCr	1 × 30 MVA	839,0
1977	MSA (RMB)	FeCr	1 × 30 MVA	869,0
1977	CMI	FeCr	2 × 32 MVA	933,0
1977	Transalloys	SiMn	1 × 48 MVA	981,0
1978	Transalloys (uprating)	FeMn, SiMn	2 × 7 MVA (was 4 MVA) 2 × 22 MVA (was 15 MVA) (replacing previous furnaces)	1001,0
1978	Samancor (uprating Metalloys)	FeMn	2 × 75 MVA (replacing 2 × 48 MVA)	1055,0
1978	MSA (RMB)	FeCr	1 × 30 MVA	1085,0
1978	MSA (Palmiet Chrome)	FeCr	1 × 20 MVA	1105,0
1978	Samancor (Metalloys)	FeMn	1 × 81 MVA	1186,0
1979	Tubatse	FeCr	1 × 30 MVA	1216,0

universities and research institutes, while the applied research took place at several ferro-alloy plants.

The Council for Mineral Technology (Mintek)—formerly the National Institute for Metallurgy (NIM)—has, by virtue of its unique position, been able to act as the major interface between the fundamental and the applied research. Thanks to the co-operation from industry and to the high calibre of the research, this country, as well as being in a favourable position with regard to mineral reserves for ferro-alloys, is in a sound position from a technical point of view. The technological developments discussed below bear testimony to this claim.

The Challenge of Increased Furnace Size

The early 1970s saw the installation of the first 48 MVA electric-smelting furnaces in this country for the production of ferrosilicon, ferromanganese, and ferrochromium, as shown in Table III. The furnaces for the latter two processes have closed-top roofs, and considerable problems were encountered on many of them at first, partly as the result of a lack of experience in operating such large closed-top units and partly as a result of certain shortcomings in design. Many of the design problems arose from the fact that overseas-based firms had designed these furnaces without due regard to the complex nature of local raw materials. The inter-electrode spacing, the furnace diameter, and the raw-material feed system were among the design features that had to be altered to suit local operating conditions.

Operating difficulties (such as break-outs of molten slag or metal) and poor performance characteristics resulted in many of these earlier large furnaces having to be rebuilt within some three to four years of their initial commissioning. This afforded an opportunity for the implementation of design modifications, which were based on the experience that had been gained by the plants during their first few years of operation. This experience was enhanced by the information gained from on-line computer-based data-logging and control facilities in many of the plants. This information had led to a far better understanding than before of the faults in the electrical design and of the control problems involved[7].

Developments in Agglomeration

One of the major limitations of the larger ferro-alloy furnaces, which had not been a severe problem on the older, smaller units, was the need for strict control of the particle size of the raw materials. Fine materials (i.e. smaller than 6 mm) were found to be extremely detrimental, not only to furnace performance, but also to the safety of the furnace operation. As over 70 per cent of Transvaal chromite ore is friable and gives rise to large quantities of fines, agglomeration became a subject of intense research from the late 1960s to the mid 1970s. Briquetting and pelletizing are the two most popular options today.

Manganese ore from the north-western Cape is physically much stronger than chromite ore, and there is no serious fines problem associated with the mining of this material. However, as some of the ores are of a low grade, consideration is being given to their upgrading, which generates additional fines. Ferromanganese furnaces are much more predisposed to catastrophic eruptions than ferrochromium furnaces, and even a small amount of fines in the feed material is likely to intensify the eruption problem. The sintering of these fines has been studied as a means of eliminating this problem[8], and tests on sintered feed have shown that its use can lead to more stable operation in large furnaces. So far no sintering plant for ores to be used in the production of ferromanganese has been established in South Africa, and the possible briquetting of manganese-ore fines is now being investigated.

Pelletizing of Chromite Ore

Research work initiated at the laboratories of Johannesburg Consolidated Investment Co. Ltd. (JCI) in 1969 on pelletizing led them in 1974 to invest in a ferrochromium plant based on technology patented by Showa Denko[9]. Run-of-mine chromite-ore fines (i.e. 100 per cent smaller than 6 mm, 90 per cent smaller than 2 mm) cannot be pelletized direct, and the ore has to be dried and milled to about 90 per cent smaller than 74 μm (200 mesh). A carbonaceous reducing agent—normally coke fines—is added to the ore before it is milled, and the pellets are prereduced in a rotary kiln. Chromite ore from the UG-2 Reef, which is soon to be processed for the recovery of platinum-group metals, can be used in this process, instead of run-of-mine ore fines[10]. The prereduction process results in an almost twofold saving in electrical energy for the smelting operation (i.e. 2 MW·h/t as against 4 MW·h/t, which virtually doubled the output of ferrochromium from a given furnace at the equivalent megawatt load). Part of this improvement is attributed to the high overall recovery of chromium and iron (more than 90 per cent).

Briquetting of Chromite Ore

Middelburg Steel and Alloys Ltd and Samancor Ltd studied the possibility of various pelletizing routes in the mid 1970s, and Mintek undertook a programme of laboratory and pilot-plant work. This research work was successful[11] but, because briquettes were considered to be more advantageous than pellets, first Middelburg Steel and Alloys[12] and then Samancor abandoned the idea of a pelletizing plant and opted for the briquetting route.

Briquetting accounts for the major proportion of the agglomerated chromite ore fed to ferrochromium furnaces in South Africa despite its disadvantages. These include the limited availability of molasses, especially in the long term, its high phosphorus content and adverse influence on metal grade, the low physical strength of briquettes in the temperature range 750 to 1000 °C, and the high loss of unreduced chromite spinel in the slag phase, i.e. the poor recovery of chromium (approximately 70 per cent). Research and development are continuing on these problems.

Use of Run-of-mine Chromite-ore Fines

Small electric-smelting furnaces (between 9 and 15 MVA) have been shown to be operable with up to 100 per cent chromite-ore fines, but larger, and especially closed-top, furnaces cannot tolerate a feed containing more than 10 per cent material smaller than 6 mm. The Tubatse Ferrochrome Plant, at Steelpoort in the Transvaal, the most recently completed ferrochromium plant in South Africa, has been specially designed to operate at loads of close to 25 MW using run-of-mine material (i.e. 70 per cent chromite-ore fines and 30 per cent lumpy ore). The development work for this plant was carried out in the U.S.A. by Union Carbide, but the expertise was implemented in South Africa.

Computer-aided Control

With the advent of larger electric-smelting furnaces, it was soon realized that improved control was necessary, especially if the production was to be optimized. In 1974, a few ferro-alloy plants, in collaboration with Mintek, embarked on projects to install computer-based data-logging and control systems[7]. The computer systems were used at first essentially for data logging on ferrochromium plants, and subsequently on a ferromanganese plant. Certain control functions, e.g., raw-material batching and electrode-power regulation, were studied.

The major control problems associated with submerged-arc electric-smelting furnaces, especially the larger furnaces, are caused by interactions between the phases of the three-phase electrical circuit[13]. Even though it had been shown that furnace design can lessen this problem (i.e. by decreasing the reactance), it was proved that computer-based control of the process using resistance values, instead of current values, was the best means of solving the problem. Another control problem that was resolved involved the batching of raw materials. Again, this problem was especially severe in large furnaces because of their large inventory of material (i.e. slow overall response to deliberate change in feed) and their sensitivity to unforeseen changes (i.e. fluctuations in the physical nature and chemical composition of the feed). Control of the particle sizes of the raw materials, especially the removal of fines, was found to be an essential factor in the achievement of stable furnace operation on these large closed units.

Once the benefits had been demonstrated and the control philosophies fully developed, these control functions were implemented on separate stand-alone microprocessors to ensure the highest possible reliability. Complementary to these, on-line control functions and improved metallurgical control philosophies were developed after a considerable research-and-development effort. Seeing that the successful operation of a ferro-alloy furnace depends, above all, on the correct proportioning of the raw materials, computer programmes were written to perform material and heat-balance calculations. In addition, models were developed to predict electrode lengths based on electrical measurements that were monitored by the computer.

Considerable increases in production rates (up to 150 per cent of original design capacity) were realized as a result of the above improvements, thereby helping to keep the escalating production costs well below the inflation rate. Mintek and several ferro-alloy producers are continuing to develop several aspects of this work.

Developments in Decarburization

The invention in 1967 of the A.O.D. (argon–oxygen decarburization) process[14] for the production of stainless steel did more than any other single development to establish the viability of the production of high-carbon ferrochromium with only a 50 to 55 per cent chromium content (as compared with the 65 to 70 per cent chromium alloy that had been the only acceptable one before). Ironically, this invention was made by Union Carbide in the U.S.A., but it has greatly favoured the production of high-carbon ferrochromium in South Africa from Transvaal 'low-grade' chromite ore. It is largely due to the A.O.D. that the production capacity of ferrochromium in the U.S.A. today is a fraction of that in South Africa.

The A.O.D. process has substantially decreased the relative demand for silicochromium and low-carbon ferrochromium, the former ingredients for stainless steel. Most ferro-alloy plants built in South Africa since 1970 have thus been able to take advantage of the demand for high-carbon ferrochromium, and have avoided the mistake of designing what may have become obsolete plants.

The decarburization of high-carbon ferrochromium, which was studied at Middelburg Steel and Alloys Ltd, can lower[15] the carbon content of the alloy from between about 7 and 7,5 per cent to between 4 and 5 per cent.

The development of the new 3CR12 ferritic stainless steel by Southern Cross Steel is probably one of the most exciting events in the ferro-alloy field in the 1980s. The A.O.D. process is again the prominent route to this alloy, which is gaining wide acceptance in South Africa and abroad.

Manganese alloys are not generally used in the same high concentrations in iron-based alloys as are chromium alloys, and thus the carbon content of the ferro-alloy that is added is not so critical. Nevertheless, techniques have been developed locally and overseas for the decarburization of high-carbon ferromanganese, but the process is not widely practised and not at all in South Africa, although the future holds some promise in this regard[16].

University Research

The growth of the ferro-alloy industry since the mid 1960s has been accompanied by a growth in research. While the individual companies involved in ferro-alloy production continue to do the development work in this field, the more fundamental research has mostly been done at South African universities. An important development was the founding of the Mintek Pyrometallurgy Research Group in 1969 within the Department of Metallurgy of the University of the Witwatersrand. The early work of the Group has been reported both in summary[17,18] and in detail[19–34].

The research goals of the Group became even more fundamental after several members of the Group had been transferred to Mintek's new laboratories in Randburg, some 15 km from the University. The topics investigated included the thermal conductivity of beds of chromite ore[35], the factors influencing the carbon content of ferrochromium[36], and slag–metal equilibria in the production of low-carbon[37] and high-carbon[38] ferromanganese. Reduction formed the subject of much of the research, including the reduction of manganese ore with ferromanganese silicide[39] and carbon[40], the effect of carbonaceous reducing agents on the reduction rates of manganese and chromium ores[41], the reactivity of reducing agents in silicon monoxide gas[42], the reduction of chromite by carbon monoxide gas[43] and by carbon[44], and the mathematical modelling of the last process[45]. In other experiments, the reaction rates of charges of manganese ore and reducing agents were measured at various temperatures[46], electrolytes of solid zirconia were used to measure the activities of chromium and chromium oxide[47], and a rotating-cylinder technique was used to measure the rate of chromite dissolution into the slag[48].

Some larger-scale work was conducted with radioactive isotopes on an industrial ferromanganese furnace to measure the movement of the burden[49].

An investigation was made of the prereduction[11] and smelting[50] of a chromite concentrate arising from the chromium ore of the UG-2 Reef, and work is proceeding on a study of the mechanisms involved in the dissolution of carbon in ferrochromium and the rate of chromium reduction from slags.

Research on ferro-alloys is being conducted at other universities in South Africa also, but to a lesser extent. This includes work on the reduction of manganese ore[51] at the Rand Afrikaans University in Johannesburg, and on the reduction of chromite[52] and manganese[53] at the University of Stellenbosch.

The overseas students in the Pyrometallurgy Group over the years have given a great stimulus to the research. The travel grants and bursaries made available by the South African Ferro Alloy Producers' Association and Mintek, which are additional to the generous contributions made by these two bodies to research equipment and running expenses, have been a major attraction to these students.

Research and Development

The areas of current applied research fall into two categories: improvements to existing methods of ferro-alloy production, and new processing methods.

Improvements to Existing Processes

The control philosophies developed by Mintek in conjunction with certain producers are being disseminated to most of the local ferro-alloy plants, and many noteworthy improvements have already resulted from this exercise. The full optimization of existing furnaces is still, however, some way off, and on-line L.P. (linear programmes) are being developed to help the industry realize this goal. An improvement in furnace performance of up to 10 per cent should be possible, but, if furnaces are to be driven to the optimum, certain non-computer control factors can become rate-determining. The Soderberg electrode is probably the most critical consideration since all the electrical energy enters the process via these conductors. Research-and-development work on locally manufactured electrode paste was one of the most important undertakings of the early 1980s, and there is considerable optimism that many of the electrode-baking, breakage, and wear problems will be solved.

Probably the greatest performance loss in most ferro-alloy furnaces is the poor recovery of metal oxides from the slag phase. Briquettes of chromite ore generate fines inside the furnace, and these fines do not dissolve to any large extent in the slag and are never reduced by carbon. Recoveries of chromium of between 60 and 70 per cent are common in ferrochromium plants utilizing briquettes containing a high proportion of fine ore, whereas recoveries of 90 to 95 per cent can be achieved on plants using prereduced pellets or very good-quality, hard, lumpy ore, e.g. Zimbabwe ore. The mechanism by which briquettes break, and possible ways of avoiding this loss to the slag in a cost-effective manner, are topics of current research. The loss of manganese oxide in slags is another topic of current investigation.

The use of hot furnace off-gas to dry and heat chromite-ore pellets is already practised at Consolidated Metallurgical Industries Ltd[10]. It seems very likely that other ferro-alloy producers will also move towards pelletizing process routes, and will therefore be able to utilize what is at present a valuable waste gas and so save electrical energy.

The rebuilding of two large ferro-alloy furnaces afforded Mintek the opportunity of investigating the contents of a furnace. As a result of these findings[54,55], and of current research into the erosion of furnace linings and heat flow in furnace hearths[56], Mintek considers it very likely that the lifespan of large high-power furnaces can be increased.

New Processing Methods

Mintek has for some time kept a watching brief over developments in plasma technology overseas[57], but it is only in the past three to four years that it has become actively involved in the pyrometallurgical processing of local minerals in plasma furnaces. With the cooperation of overseas and local companies, Mintek has installed a multi-purpose plasma pilot plant, which has already helped to establish confidence among South African producers in the exciting future possibilities for this technology.

Plasma-arc Systems (Non-consumable Electrodes)

The thermal plasma is normally generated by the passing of a high current between non-consumable counter-electrodes for an a.c. system, or from a non-consumable cathode to an anode (usually the bath) for a d.c. system. The former system is sometimes termed a non-transferred plasma-arc heater, and the latter a transferred-arc plasma. These two subdivisions of applied plasma technology are being used for two rather different process methods. The non-transferred plasma system has been shown to be most readily suited to complementing, or even replacing, the conventional blast-furnace tuyère while the transferred-arc plasma lends itself to the configuration of the conventional open-arc or submerged-arc electric furnace.

Scale-up to an economic size is still some three to five years away for ferro-alloy processes (i.e. processes that use materials of lower value), but plasma has already gained acceptance as a processor of higher-value materials. Plasma units of up to 20 MW are not beyond the present technical capability and, depending on market conditions, will probably be installed in the near future both abroad and locally.

Diffuse Plasma-arc Systems (Consumable Electrodes)

The concept of the extended or diffuse plasma arose from bench-scale work at the University of Toronto[58,59]. A 100 kW three-phase a.c. diffuse-plasma furnace system consisting of three hollow consumable graphite electrodes that are inclined at 45 degrees from the vertical and are symmetrically spaced was installed at Mintek early in 1981. Argon, carbon monoxide, nitrogen, and other suitable gases can be passed down the hollow electrodes to form a plasma arc at their bases or tips. This plasma arc is considerably more stable than the original carbon arc (i.e. an arc without the introduction of gas), and it affords excellent heat transfer to the process. Furthermore, the volume of the arc can be extended by several orders of magnitude without causing the arc to become extinguished. This furnace has been used successfully in a number of pyrometallurgical processes, including the processing of ferro-alloys.

The motivation for this particular approach to plasma is the fact that the metallurgical industry has a large capital investment in existing arc furnaces. The plasma facility at Mintek is currently being used in an evaluation of the specific aspects of plasma-arc technology that can be introduced into the existing electric-smelting furnaces. Fundamental research into three-phase systems and arcing phenomena forms an important part of this evaluation.

Fluidized-bed Reactors

The direct use of plasma-based gas reformers for shaft-furnace DRI processes and the coupling of fluidized-bed reactors and plasma furnaces for the production of liquid pig iron have been proposed by SKF in Sweden[60]. Fluidized-bed reactors are probably the best means of achieving good mixing of gases and solids at temperatures of up to about 1000 °C. Either reducing or oxidizing gases can be used for the pretreatment of ore fines.

Research work currently being undertaken by Mintek includes an examination of the pretreatment of chromite and manganese-ore fines before being smelted in plasma furnaces, or before being formed into briquettes or pellets for subsequent conventional smelting in a submerged-arc electric furnace.

The major problem with endothermic reactions in fluidized-bed reactors is the achievement of sufficient heat transfer from the hot (low-density, low-enthalpy) gases. Nevertheless, the use of fluidized-bed reactors in the ferro-alloy field holds considerable promise.

Conclusions

Predictions of impressive growth for the ferro-alloy industry were made at the Seventh Commonwealth Mining and Metallurgical Conference[61]. What actually transpired in South Africa exceeded even the wildest dreams, as can be judged from the facts presented in this paper, in that a growth of almost 12 per cent per annum was realized. The most recent growth can be attributed partly to a shift in production from Developed to Developing Countries caused by the oil crisis, but the main reasons for South Africa's growth are her large reserves of chromium and manganese ore, her relatively cheap electrical costs, and the way her industry has accepted the challenges of new processes and larger furnaces, and has undertaken the necessary research-and-development work.

Now that a more or less steady situation has been achieved in the growth pattern, the only factor, apart from normal growth, that could stimulate further rapid growth is a greater market demand for stainless steel and, possibly, market acceptance of new grades of chromium steels. Over the next twenty-one years, we may even find that the growth rate of 12 per cent per annum has continued, in which case we could expect announcements regarding new expansions in the near future.

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Thirteen chromite reefs occur in the Bushveld Complex and extend in a large circle from Rustenburg in the south-west to Potgietersrust in the north and Lydenburg in the east. The true extent of this complex can be measured from the fact that active mining operations on the eastern flank are more than 400 km from those in the west, and the northern deposits are mined some 170 km from the equivalent operations in the south.

Reserves of Coal and Anthracite

Each of the Republic's four provinces has substantial coal reserves, which occur in five major basins. These reserves, which had previously been estimated as 26 000 Mt of recoverable material, were recently estimated as 61 000 Mt after a country-wide survey. Largely due to the extent of the resources and to the ease with which the coal is recovered, the country's primary-energy requirements are based predominantly on coal, with thermal stations being sited at selected coal fields.

This relatively cheap energy is one of the major reasons for the cost advantage enjoyed by local domestic producers on the international market for commodities like ferro-alloys that have a high energy cost component. In this regard, it is particularly interesting to compare the costs per kilowatt-hour in the U.S.A. (4,5 U.S. cents) and Japan (5 U.S. cents) with that in South Africa (2,1 U.S. cents in 1979)[5].

It must be borne in mind that coal is also used as a reducing agent in submerged-arc ferro-alloy furnaces, and therefore serves a dual role in the economy[6]. In addition to the factors already mentioned, South African operators have to a very large extent learnt to partly replace traditional coke as a reducing agent in the production of ferro-alloys with raw coal, thereby contributing still further to the considerable cost savings that have been substantiated in the open markets of the world.

Infrastructure

The South African transportation network is impressive by any standards, and owes its size to a continued programme of expansion and modernization. The initial impetus came after the Second World War when, owing to increasing exports, the loading facilities at the major ports became inadequate. During the early 1960s, a freight terminal was constructed at Port Elizabeth, and, to speed up the transportation of iron and manganese ore, the railway line from Kimberley to Sishen was electrified. In spite of these improvements, the demand still imposed strains on the system, and, at the instigation of Iscor, work began on the special ore-carrying railway that runs from Sishen to Saldanha Bay on the western coast. This rail link is 860 km long, and at present carries more than 15 Mt of export iron ore annually. The harbour has been developed to accommodate ships with a dead-weight capacity of 250 kt.

On the South African east coast, a railway joins the coal and anthracite beds to the new port of Richards Bay, which is some 200 km north of Durban and was developed from a greenfield site to a coal terminal because of its proximity to the Witbank and Natal coalfields. This system will soon handle close to 40 Mt annually. Extensive construction work is at present under way to enable the port to handle bulk commodities other than coal.

History of South African Ferro-Alloys

In view of the above, it is not surprising that the South African ferro-alloy industry should be as large as it is today, although it must be pointed out that its beginnings were humble. Table III summarizes the history of the industry, and the exponential growth pattern is illustrated graphically in Fig. 2.

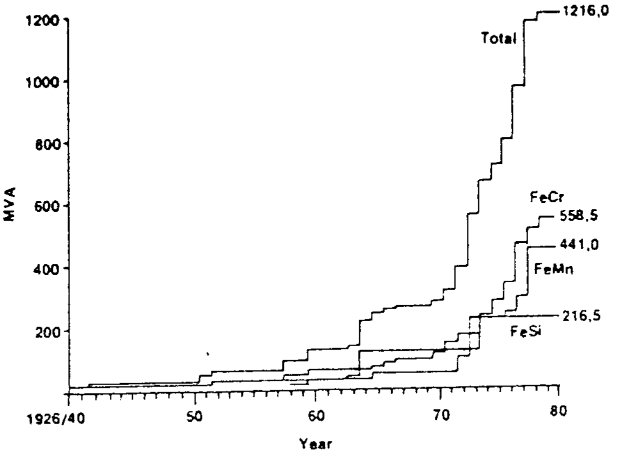

Fig. 2—The growth of the ferro-alloy industry in South Africa since 1940

The growth of the industry can conveniently be divided into three distinct phases beginning in 1926, when, for almost the next twenty years, Rand Carbide was the only operator of submerged-arc furnaces in the country. It was only in 1942 that Amcor, the forerunner of Samancor, entered the ferro-alloy field. At the time of the Commonwealth Mining and Metallurgical Congress in 1961, the total installed capacity of the industry in South Africa was a mere 123 MVA, and the same year marked the beginning of the second phase in the domestic industry. The third, and most rapid, phase began in 1970, when the total installed capacity was 297,5 MVA. Within a mere three years this total was doubled, and within eight years was quadrupled, bringing the total installed rating, excluding the present-day carbide and pig-iron facilities, to an estimated 1216 MVA.

Technological Developments in Industry

This dramatic growth in total installed electric-smelting furnace capacity was accompanied by an impressive increase in the individual MVA rating and physical size of the furnaces. These trends necessitated a wide range of technological developments in the industry, many of which occurred as a result of joint efforts by the ferro-alloy industry and various research-and-development organizations. The fundamental research was conducted mostly at

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Presenter: N.A. Barcza

Discussion

W.A. Gericke: Please comment on the fact that, although substantially successful development took place in the pelletizing of chromite fines, two major ferrochromium producers opted for the briquetting route. Numerous disadvantages became apparent with briquetting. In retrospect, would you say that briquetting was indeed the correct route?

N.A. Barcza: This is a very topical question and one that has been hotly debated for a number of years. As Mr Gericke mentioned, considerable research work has gone into pelletizing tests, with the production of both non-prereduced and prereduced pellets, in the interests of solving the fines problem with South African chromites. Although briquetting is the less capital-intensive operation, there are certain problems associated with its use. While being handled, briquettes generate a certain amount of fines, which have to be recirculated, somewhat reducing the capacity of the plant. However, there have been several improvements in solving these problems in the industry. Furthermore, there is a limitation on the amount of molasses available from the sugarcane industry, and phosphorus contamination arising from the use of molasses is to be avoided in the metal. Briquettes do not have sufficient physical strength at more-elevated temperatures, i.e. 750 to 1000 °C, and their disintegration tends to lead to a substantial loss of unreacted chromium fines in the slag. This loss means that the recovery from briquettes is approximately 70 per cent, as compared with the 90 to 95 per cent that can be obtained with pellets.

A. Granville: At the Minerals Bureau, we have been looking at the adequacy of the South African reserves of coal in general, and of specific types. Would Dr Barcza care to comment on future developments, both with regard to quantity and type?

N.A. Barcza: As you all know, the ferro-alloy industry is at present going through a recession, and the availability of suitable reducing agents is therefore not such a problem. Obviously, when there is a high demand and high production is required, our supply of reducing agents, particularly coke and char, can in certain circumstances be stretched. The industry has had noteworthy successes in moving away from coke and char to raw coal, and this has increased the choice of supply of reducing agent. One further point I would like to mention is that, in the handling of reducing agents, a large amount of fines is generated. Therefore, one of the attractive features of the plasma-arc technique is that it will readily accept these fines.

C.W.P. Finn: I would like to comment further on the role of carbonaceous reductants. Extensive tests have been done at the Pyrometallurgy Research Group at the University of the Witwatersrand and at Mintek. Ferro-alloys are especially tolerant with respect to the type of reductant. Indeed, just about anything containing carbon seems to work, be it raw coal, metallurgical coke, or char. As part of the research on the ferromanganese furnace 'dig-out' referred to in the paper, all these various reductants were found to be in a similar form inside the furnace, i.e. the coal was charred. Furthermore, similar reduction kinetics were observed for South African manganese ores with all types of reducing agent.

C. Brindley: What facilities will Mintek have in the near future for the treatment of ore fines for the production of ferro-alloys by plasma technology?

N.A. Barcza: The plan at Mintek is to do work on the three options discussed on a small scale (100 kW), i.e. the diffused arc and the transferred arc, both of which have been thoroughly tested for about two years; in addition, we are negotiating with a supplier for a non-transferred arc unit. Also, we are busy installing a large-scale transferred-arc furnace. It is a 3.5 MVA system, which we hope to operate at about 1.5 MW.