EXECUTIVE SUMMARY

1. HISTORY OF DEVELOPMENT

Charge Chrome is a form of High Carbon Ferro Chrome, with relatively lower chromium content, varying between 50 to 60 percent. The development of Charge Chrome industry is directly related to the developments in the alloy steel production technology.

Chromium is an essential alloying element for the production of all types of stainless steels and special categories of alloy steels, on account of the special properties chromium imparts to Steel. After the initial experimentations and practices, during "Twenties & Thirties", followed by the alloy steel manufacturers using the Iron Ore and Chrome Ore process, the usage of costly Low Carbon Ferro Chrome as the medium for introduction of additional chromium was established, during "Forties". This was followed in 1945, by the use of Ferro Chrome Silicon. Use of Low Carbon Ferro Chrome and Silico Chrome, for chromium addition, was continued till "Sixties" when, around 1964 (VOD initiated in 1952 but commercialised in 1964) and 1968, the Vacuum Oxygen Decarburisation (VOD) and the Argon Oxygen Decarburisation (AOD), respectively, were developed and commercialised. Then, in 1972 the CLU (Creusot-Loire Uddelohm) process was developed. These three processes, in particular the former two, ushered in a revolution in the alloy steel production technologies. Quite a few other similar process like ASEA-SKF, ASV,DH, Vac Metal, etc., were also developed in the meantime.

With the advent of AOD and VOD technologies, the use of High Carbon Ferro Chrome, for introducing chromium into steel with much improved process economics, was established. However with the worldwise standardisation of these technologies, not only the use of H.C. Ferro Chrome was established, it was also established that Ferro Chrome, with even 50% chromium content, can be efficiently used in the production of stainless steels & other special alloy steels. This resulted in the arrival of Charge Chrome as the most economic and established medium of chromium addition to steels. Since the Charge Chrome production technology permits use of medium grade ores as well as high grade Ferro

Chrome, the charge chrome was fast accepted by all chrome alloy producers of the world, in view of the fast depleting resources of high Cr/Fe ratio lumpy chrome ore.

2. GENERAL

Chromium was discovered by Louis Vauguelin in 1798 and was first obtained, in its elemental form in 1859, by WHOLER. However, chromium as a commercial metal, was subsequently established as a medium for the introduction of chromium into steel, to get the required beneficial effects of Chromium imparted to Steel. Chromium increases the hardness, strength, yield point, elasticity and resistance to corrosion, heat, acid, etc. Therefore, chromium is essentially used for the production of all varieties of stainless steels: Heat & Acid Resistant Steels: Structural, Tools & other special categories of steels. Chromium steels are also used for the manufacture of Ball and Roller bearings.

3. MANUFACTURING PROCESS

The electric smelting process necessitates the use of a highly permeable lumpy charge for easy dissipation of reaction gases and smooth functioning of furnaces. Therefore the concentrates and fines are agglomerated first, since they cannot be utilised directly. Out of the several agglomeration process, available as alternatives like modulizing, sintering, pelletizing and briquetting, the last is used in this country by three units. Of the four major Charge Chrome units operating, one use "Pelletizing". Pelletization route is also most used, so far, in other countries of the world.

For Pelletization there are five known processes:

(i) Outo Kumpu 'Oy of Finland,

(ii) S.R.C. Process of Showa Denko,

(iii) Lepol Process of Polysius AG Germany,

(iv) N.K.K. Process, Japan,

(v) Cobo Process of Sweden.

OMCAL plant, in India has adopted Outokumpu 'Oy process. The two important steps in Pelletization are:

(i) Grinding the ore to very fine mesh size, about 80% below 200 mesh, and then to form balls in a Disc Pelletizer,

(ii) Heat hardening the green pellets, from the Pelletizer, in a shaft sintering furnace to give sufficient strength to the pellets, in order to encounter the smelting conditions.

The briquetting process of agglomeration is used by FACOR, IMFA, and ICCL plants, in India. In this process the chrome ore fines and the concentrates (grain size preferably upto 1 mm, or still better, to 0.5 mm) are mixed with suitable binders and/or lime, and fed into a double roll briquetting press, to be moulded into shapes, usually pillow like shapes of 50 x 40 x 25 mm or 76 x 46 x 22 mm in dimensions., by the application of external pressure on to the material. In Indian plant Moalsses is the usual binder used.

Preheating: Pellets are preheated, either in a Rotary Kiln or in a static preheating equipment. Using the carbon monoxide gases, generated in the smelting furnace or Fuel Oil or both. Preheating makes it possible to cut the electrical energy consumption figure by as much as 0.7 to 0.8 MWH per ton of Charge Chrome, produced in the smelting furnace.

Smelting: The electro thermal process is generally used for the production of Charge Chrome, through now there are quite a few plants with PLASMA technology. And quite a few other electrical power saving technologies, like Kawasaki, Inmetco, Krupp Codir, etc. process are in the final stages of commercialisation. In fact Kawasaki process is already being economically operated in Japan.

In the generally used electro thermal process, the furnace is either a closed-top or semi-closed one, operated on a continuous basis. In which the chrome ore is reduced by carbon, with electric power producing the high temperature necessary for the reactions. The stationary type submerged arc smelting furnace is provided with three electrodes, Soderberg continuous self-baking type, having a variable pitch circle. The smelting operation aims at reducing the Iron and Chromium Oxides, while major portion of the other constituents of the ore go into the slag. The slag volume is generally 1.2 to 1.4 times, in weight of the metal produced.

In India, the reductant generally used in Charge Chrome production, are coke and coal, a judicious mixture of which is decided purely from techno-economic reasons, inspite of the high ash contents of these reductants leading to higher slag volumes & higher phosphorous in the metal. However, economics permitting, imported coke or low-phosphorous Giridih coke or similar suitable reducing agent is made a constitutent of the reductant mix for charge chrome furnace, in order to control the total imput of impurities.

The following steps are involved in the production process of charge chrome:

(i) Removal of voletiles & moisture from the charge thru heating of the charge by the latent heat of the off gases of the furnace,

(ii) Reduction of Iron & Chromium oxides, with simulataneous formation of Iron & Chromium carbides.

(iii) Melting of the reduced elements, resulting in formation of molten ferro-chrome.

(iv) Formation and melting of slag.

(v) Reduction of chromium and silicon from the slag.

The principal reactions taking place in the furnace are:

$$2/3\,Cr_2O_3 + 18/7\,C = 4/21\,Cr_7C_3 + 2\,CO$$

$$FeO + C = Fe + CO$$

$$1/3\,Cr_7C_3 + 1/3\,Cr_2O_3 = 3\,Cr + CO$$

The melting temperature maintained in a charge chrome is around 1600°C. The operating voltage for the process varies between 150V to 260V, averaging at around 200V.

The slag and metal are tapped at periodic intervals , once in every 2 to 3 hours, from generally one tap hole. While the metal cakes are broken into various sizes, as per customer's requirement, the slag is granulated with water for easy disposal.

Gas Cleaning: The off gases from the submerged arc furnace is cleaned in venture scrubbers for reuse in sintering furnace and preheating kiln and/or to pre-heat the electric furnace charge, as the case may be.

4. RAW MATERIALS

Chromite: Lumpy, as well as friable chromite ores and fines of both high and medium grades are used as the major feed. However presently concentrates, beneficiated from low grade lumps and fines, are used in a major way. The minimum required Cr/Fe ratio of the ore should be 1.8:1 but preferably 2.0:1.

Out of the various possible reductants available in India judicious combination of Indian coke and Indian coal (At times imported coke) is used in Indian charge chrome units. The reductant should posses the following properties:

(i) Low ash,

(ii) Low Phosphorous,

(iii) Large reactive surface,

(iv) Low volatile matter content,

(v) High electric resistance,

(vi) Sufficient mechanical strength, and

(vii) Minimum cost.

Fluxing agents are chosen from Quartzite, Dolomite, Magnesite, Bauxite, Limestone, etc. And the decision varies from plant to plant.

Consumption Norms: Consumption norms for major raw materials per ton of saleable product would be,

A chromite ore	2,300 to 2,600 kgs	
Fluxes	220 kgs to 500 kgs	
Electrical Energy	1.	Around 3050 KWH to 3200 KWH (preheating facilities).
	2.	Around 3800 KWH to 4000 (with only briquetted charge without preheating)

5. LIST OF MAJOR CAPITAL EQUIPMENTS

The equipments for a typical charge-chrome industry is broadly classified into the following groups on the basis of the functional requirements:

(i) Raw material storage, handling and preparation.

(ii) Agglomeration.

(a) **Pelletizing Route :** The system will include grinding and filtering facilities, Disc Pelletizer, shaft type sintering furnace, etc.

(b) **Briquetting Route:** It will include Double Roll press, in addition to other supporting facilities:

(iii) **Raw Materials Handling for Smelting:**

This will include, in addition to the common facilities for such systems for dosing & charging, preheating Kiln (in plants using hardened pellets as the feed), etc.

(iv) **Smelting Furnace and Auxiliaries:**

This will include furnace of circular design having a stationary hearth and semi-closed or closed top design, with three phase self-baking continuous soderberg electrodes; electrode holder assembly, as well as the electrode slipping mechanism; copper contact clamps holding the electrodes; copper bus bars; water cooled copper bus-tubes; connector terminal and copper flexibles.

(v) **Tapping & Finishings:**

The cast house is generally equipped with mud-gun for closing the tap holes, Oxygen lancing system for opening of tap holes, refractory lined ladles for holding the taped out metal and slag, slag granulation plants, suitable overhead cranes, crane weighers, mobile breaker, crusher, etc.

6. STRUCTURE OF THE INDUSTRY

Although chromite mining in India started around 1903 there was no ferro-chrome production in the country till 1968. Hence most of the chromite ore was exported. India exported about 3.84 million tonnes between 1903 to 1980. The current production rate of chromite ore in the country is between 0.7 to 0.9 million tonnes per annum.

In 1986, India attained a production of 90,000 tonnes of FeCr/charge chrome. Prior to implementation of the OMCAL, and FACOR units, the production of FeCr was only about 20,000 TPA. The situation has changed dramatically due to the commencement of production in the export oriented units.

Estimated reserve of chromite ore in the country is about 140 million tones, and about 127 million tones are available in the Sukinda valley of Orissa state.

7. LICENCED/INSTALLED/PRODUCTION CAPACITY

The total licenced and installed capacity is 207,500 TPA FACOR and IMFA plants were commissioned during 1983, OMCAL in 1986 and ICCL in 1990.

Investment: The fixed asset investment made in various charge chrome plants are:

(a)	OMCAL	—	Rs. 6700 lakhs
(b)	FACOR	—	Rs. 3200 lakhs
(c)	IMFA	—	Rs. 1450 lakhs
(d)	ICCL	—	Rs. 4319 lakhs

Sales Turn over: The sales turnover for the various producers in 1989-90 is given below:

(a)	OMCAL	—	Rs.29.28 Cr.
(b)	FACOR	—	Rs.57.56 Cr.
(c)	IMFA	—	(8764 t)
(d)	ICCL	—	Nil

8. PROBLEMS FOR CHARGE CHROME INDUSTRY

- Highly fluctuating international market both in respect to its prices and demand.
- Non-availability of high grade lumpy ore.
- Poor quality reductant as well as electrode paste.
- Power cuts and increasing power tariffs.
- Non-optimisation of utilisation of by-products, such as slags, furnaces gases and fine ores.

9. FINES AVAILABILITY AND UTILISATION

The Sukinda valley area of Orissa State, has a reserve of about 160 million tonne of different grades of ore fines. With the technological developments in the field of charge chrome production, several producers such as OMCAL, FACOR, ICCL, etc. have adopted agglomeration techniques for utilising these ore fines. FACOR and Tata Steel, have implemented beneficiation plants having capacities of 65,000 and 13,5,000 TPA respectively. Orissa Mining Corporation is also setting up its own beneficiation plant with an installed capacity of 80,000 TPA.

Efforts for Utilisation of Fines: Bhaba Atomic Research Centre have developed a pilot plant for benificiation of Sukinda Valley chromite ore, based on which OMC is setting up a commercial plant of 80,000 TPA capacity. Ferro Alloy Corporations has set up a beneficiation plant based on the process developed by RRL, Bhubaneshwar. For Tata Steel's benificiation plant, laboratory tests were initially undertaken by RRL, Bhubaneshwar, Sala International Sweden, Nittesu Mining Company of Japan, Voest Alpine Industriagen, Austria. The pilot plant test was conducted at FACOR, Garividi.

10. TECHNOLOGY STATUS OF INDIAN INDUSTRY

India has the 6th largest installed capacity (207,500 TPA) of ChCr/HCFeCr in the world.

The four EOU's, the major producers of charge chrome in India, are located in the chromite rich zone of Orissa State. They are:

- OMC Alloys Ltd., (OMCAL).
- Ferro Alloys Corporation (FACOR).
- Indian Metals & Ferro-Alloys (IMFA).
- Indian Charge Chrome Ltd., (ICCL).

Several smaller units, having a total net installed capacity of 67,000 TPA have come up, and primarily cater to the needs of domestic market. Foreign collaborations have been approved for the export oriented units only. The smaller units have arranged the technology as well as the equipments from the indigenous sources. The Export Oriented Units (EOUS) are based on either the briquetting or pelletising technology and use low grade chromite ore fines.

11. INTERNATIONAL SCENARIO

About 83 percent of the world chrome ore reserves are found in South Africa. The reserves of high grade coal is also quite substantial. Of the rest 17 percent of the world reserve nearly, 11 percent is accounted for by Zimbabwe alone.

International Trend: The process adopted world wide for production of charge chrome is smelting of agglomerated ore with low ash coke in a submerged electric arc furnace. Efforts for optimising the production technique are still continuing. Specific developments have been made in the charge chrome production technology involving the use of 100 percent chromite ore fines, waste heat recovery system / methods, mechanisation & automation of the process using computer control methods, etc.

Utilisation of Fines: Due to rapid depletion of the high grade chrome ore, several manufactures of world repute like Union Carbide, & Kawasaki Steel Company have invested and experimented to establish alternate methods of production, using low grade ore fines.

With new plants coming up in India, Sweden, Turkey and South Africa, meeting the demand for Stainless Steel would not be a problem, even with an annual growth rate, of consumption, of 3 percent. Moreover, Acesita in Brazil, Tand Eng. in Tawain and Salem in India, are all expanding their existing capacities. Besides, countries like Cuba, Indonesia, Romania and Greece, etc. intend to start stainless steel production shortly.

With respect to the international market, the out look for ferro-chrome in stainless steel industries is promising. The annual growth in consumptions of ferro-chromium is likely to be about 2.5 to 3 percent.

International Manufacturers: Developments in stainless steel production technologies, like AOD, ASEA — SKF ASV, VOD/LOVAC and vacuum metallurgical process have resulted in replacement of LCFeCr with HCFeCr or charge chrome, for chromium addition in steel. In 1986 total US chromium consumption for stainless steel production was about 268,000 tonne, of which 94 percent was charged in the form of high carbon ferro-chromium.

International Users: Middleberg Steels and Alloys reports that Western world consumption of charge chrome totalled to 1.856 million tonne in 1985 and expected further increase in the consumption to 2.16 million tonne by 1990-91. Seven western world countries account for about 80 percent of the world consumption of charge chrome. Japan is the highest consumer with 634,200 tonne in 1986.

12. STATE OF ART TECHNOLOGIES

Charge Chrome production technology has undergone continuous development with respect to equipment design and process control. The significant improvements in this field are automatic feeding and process control systems as well as closed furnace design for utilisation of waste heat in the off gases.

Preheating: Sintered pellets prior to charging in the smelting furnace, are preheated in a rotary kiln as a mode of energy saving. In Kuromoto Iran Works (KIW) of Nippon Kokan in Japan, a vertical annular shaft furnace, fired with fuel gas is used to harden chromite ore pellets before changing them into electric furnace. A travelling grate kiln, heated by the off gases is used in the plant of Consolidated Metallurgical Industries (CMI) at Lydenberg, South Africa. Maximum energy savings, by preheating the charge at 1500K, is 880KWH per tonne of alloy, a reduction of about 26 percent in electrical energy.

Pre Reduction: Composite pellets (Chromite and coke fines) are currently pre-reduced in a rotary kiln fixed by pulverised coal and air at CMI plant in South Africa. The degree of pre-reduction attained is about 55 percent for chromium and 80 percent for iron.

Recently Kawasaki have demonstrated pre-reduction of chromite in a fluidised bed reactor introduction of methane with hot reduction gases, in a pilot plant.

SRC Process: Showa Denko K.K. (SDK) of Japan developed the solid state reduction process, for production of high carbon ferro chrome, in the year 1968 and commercialised it in 1972, at Shunan Denko KK (SKK), Japan. In this process, the pellets are pre-reduced in a rotary kiln, using pulverised coal, and the pre-reduced charge is fed into a closed top arc furnace. Due to low volume gas generation in the electric furnace the gas cleaning and recovery system is compacted and the investment is low.

Kawasaki Process: The process, utilizes a smelting reduction furnace having two stage tuyere, of coke packed bed type, with or without a pre-reduction furnace. In both cases the, pre-reduced or raw charge is injected through a gravitational transportation system over tuyere with hot air. The injected ore is easily melted in front of the tuyere and the molten ore is reduced to metal as it passes through coke bed.

CODIR Process: The CODIR Process for the use of chromite ore fines uses a rotary kiln as reduction aggregate and requires raw materials such as, chromite ore fines and coal with phosphorous content of max. 0.01 percent and sulphur not more than 1 percent. Fixed carbon of coal should exceed 58 percent, to reduce waste gas generation.

Plasma Smelting: Thermal plasma used for metallurgical applications is a partically ionised gas (around 2%). It is easily produced by passing gas through the electric arc between electrodes. The technical feasibility of utilising low grade ore fines and coal fines in production of

Ferro-chromium has been established in laboratory scale by several organisations. SKF Engineering using a vertical shaft plasma reactor have produced 50,000 TPA of FeCr. Middleburg Steel and Alloys, South Africa (MINTEK) are operating a pilot plant with 60,000 TPA capacity to produce ferro-chromium by using a hollow graphite cathode transferred arc plasma.

13. RESEARCH AND DEVELOPMENT

The Charge Chrome industry needs to concentrate on the following areas for further development:

— Improved methods for beneficiation of chromite ore fines as well as reductant materials.

— Automation/Instrumentation of the process for better yield.

— Better manufacturing and material management techniques.

— Design aspects of critical equipments.

Research and Development activities undertaken by the National Laboratories are:

— Chrome ore beneficiation by Bhaba Atomic Research Centre.

— Ore beneficiation process development by RRL, Bhubaneshwar

— Briquetting process development by RRL, Bhubaneshwar.

Several ferro-chrome producers have undertaken developmental activities by associating with other organisations, Indian or Foreign. The major efforts are given below:

— FACOR improved upon the basic beneficiation process developed by RRL, Bhubaneshwar and has produced +2 percent Cr_2O_3 concentrates from inferior grade ore.

— FACOR have manufactured, indigenously, a 16 MVA smelting furnace with minimum import contents.

With assistance from ELKEM, Norway, FACOR has conducted trials for using chromite ore fines directly in the furnace.

14. TECHNOLOGY ABSORPTION

14.1. FACOR's charge chrome plant adopted the furnace design of ELKEM, Norway, subsequently modified & re-inforced by TANABE. FACOR, with the help of their own In-house R & D efforts have been able to completely absorb the technology.

14.2. IMFA & ICCL have also adopted the technology from Elkem Norway. These units have absorbed the technology fairly well. The major constraints are power shortages & temporary non-availability of raw-material.

14.3. OMC Alloys a subsidiary company of Orissa Mining Corporation have unsuccessfully adopted the technology from Outokumpu of Finland. The reasons for their lack of success may be attributed broadly to the following :

- Inferior quality raw material used, compared to the analysis given for furnace design.
- Improper control of moisture in the filter cakes.
- Preheating in the rotary kiln is rarely practised due to indifferent power supply.

15. TECHNOLOGY GAP

15.1. Certain critical components are yet to be imported for the newer installations. Specific equipments/system supplied by the original equipment suppliers are as below:

- Electrode column and control system.
- Hydraulic pack.
- Critical control equipments.
- Engineering design.

15.2. Inadequate controls for the input materials is resulting in poor yield. For this technological gap the raw material management system is required to be improved.

15.3. Minimal pollution control measures, leading to reduction in efficiency of personnel and poor productivity. Minimal attempts for utilisation of waste heat recovery systems.

15.4. In most of the modern smelting furnace plants world wide, the manual control of operational parameters have been replaced by computer controlled systems, for monitoring the parameters continuously. In India most of the plants are still dependent on manual control systems.

15.5. The reductant materials and the electrode paste, available in the country, are not of suitable grade. Hence attempt must be made to upgrade such materials to grades suitable for charge chrome production.

16. RECOMMENDATIONS

(i) It would be necessary to bring down the cost of production to make the product competitive in the international market.

(ii) Charge Chrome producers in general may take necessary steps to beneficiate and aggolmerate the low grade ores and fines of all grades for their economic exploitation.

(iii) Effort should be made by the producers to adopt suitable waste heat recovery systems, coupled with pollution control measures for the benefit of the industry as well as the environment. Effective indigenisation of the pollution control epuipment by the indigenous engineering industries should also be undertaken.

(iv) Necessary steps may be taken to develop suitable reductant materials, such as formed coke from non-coking coal to meet the needs of the charge chrome as well as other furnace alloy industries.

(v) Continuous power supply at an uniform tariff may be provided to the charge chrome industry ensuring at least 80% of their requirement.

(vi) Incentives and compensation may be provied to the charge chrome producers undertaking R & D activities at their own plants.

(vii) Available R & D Institutions in the country may associate themselves with the existing industries and indigenous equipment suppliers for improvisation in technology, resulting in improved coeration parameters, coupled with designing of necessary equipments to commercially adopt the same.

(viii) Further implementation of Ferro-Chrome/Charge Chrôme units may be permitted only if they are set up with in-built facilities to 100% chrome ore fines, of all grades, as feed. It should also be desirable for all new units to adopt new technologies with minimum consumption of electrical energy.

(ix) Processes developed by Kawsaki, Inmetco, Corex, etc. may be developed further with Indian raw materials and commercially adopted.