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EAF Stainless Steel Dust Processing

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Abstract

During the production of stainless steel iron between 30 and 70 kg of dust and fine waste is generated per ton of steel. Mintek has developed the Enviroplas™ process for the treatment of solid wastes from the metallurgical industry, especially steel plant dusts, without requiring agglomeration to produce inert slag and at the same time recover metal values such as nickel, chromium and zinc. The products that are generated in the DC arc process are usually a metal and a non-toxic slag, which are tapped from the furnace in liquid form. The metal is mainly composed of iron, chromium, nickel and manganese.

Mintek has successfully processed around 1700t of AOD/EAF dust on a toll treatment basis in order to recover the contained Cr and Ni. The metal produced contained 18 per cent Cr, and 6 per cent Ni. All slag samples tested conformed to US EPA regulations for disposal. The chromium and nickel recovery to metal was 92 and 94 per cent respectively, on a once through basis i.e. no baghouse dust recycle.

The process has been adapted for operation on an existing ferrochromium furnace at Mogale Alloys. This involved refurbishing the existing 40 MVA DC arc ferrochromium furnace and using the know-how of the plant management to achieve successful operation.

1. Introduction

The Stainless Steel Industry has been growing at about 6% per year for the past thirty years. Growth in the developed countries has slowed down in recent years to about 3%. However the growth rate in Asia is over 10% and more recently China is projected to reach over 25%. Stainless Steel alloys contribute to sustainability because of their favourable long in service use characteristics. This is because of the good corrosion resistance and other durability properties of the wide range of types of stainless steel that can be customised for purpose.

The first stage in the production of stainless steel from ferrochromium nickel cathode and ferronickel and the recycling of scrap takes place in the Electric Arc Furnace (EAF). The operating characteristics of the EAF result in a small proportion of the off gas containing fume and entrained dusts. These sub-micron materials are hazardous because of their heavy metal content some of which are partly soluble i.e. hexavalent chromium which is toxic. The disposal of these fine dust-containing materials is expensive and requires class one landfill sites. However there are nevertheless ongoing potential liability issues where these dusts are landfilled. The treatment of these EAF dusts to recover the valuable metal contents i.e. nickel, chromium, molybdenum and iron has been practised in several regions over the past twenty years for environmental and economic reasons. A number of competing technologies have emerged and new approaches are being developed. The technologies that have been commercially implemented include:

- The rotary hearth kiln pre-reduction of pellets followed by submerged arc furnace smelting (Inmetco USA, other plants in Japan Nippon Steel and Taiwan),
- The non-transferred plasma arc heated coke-filled shaft kiln with dust injection via tuyeres (Scandust Sweden),
- The smelting of briquetted dust in a conventional submerged arc furnace (Metal Europe France),
- The DC transferred open arc furnace (Heckett Multiserv Italy and Mogale Alloys South Africa).

Mintek has over the past thirty years developed the application of the DC arc furnace to various metallurgical processes including ferrochromium, ferromanganese, ferronickel, stainless steel dust processing, cobalt recovery from slag, lead zinc slag and carbon steel dust processing, ilmenite smelting and atmospheric magnesium production. The participation in the application of Mintek's technologies on a commercial basis has been a recent development for Mintek with the establishment of Mindev (Pty) Ltd. Mintek approached SAMANCOR (Pty) Ltd, that was until recently owned by BHP Billiton and Anglo American in 2001, when its Palmiet Ferrochrome Plant near Johannesburg South Africa was closed due to poor market conditions in the ferroalloy industry. Mintek proposed that the existing 40 MVA DC arc furnace be considered as a suitable facility to process the stockpiles and current arisings of stainless steel dusts and related wastes from the Columbus Stainless Steel Plant some 200 km away. Some of these stockpiles are located at the Middelburg Ferrochrome plant belonging to SAMANCOR so this approach was seen to offer a potential solution to the environmental needs of the industry. SAMANCOR responded positively and suggested that Mindev collaborate with former management of the Palmiet Plant (PGR Investments) to re-establish the operation. PGR Investments had proposed that the plant be restarted to produce ferrochromium again.

The plant was refurbished during late 2002 and commenced operation in 2003 as Mogale Alloys under a lease contract with SAMANCOR, with PGR Investments as the plant operators. The plant was recently purchased by the shareholders who include a BEE (Black Economic Empowerment) partner Sebeso (50:50 Leswikeng and Safika), Atoll (40:40 Bateman and Mintek), PGR Investments 17, and an Employees Trust. The DC furnace has operated as both a ferrochromium producer and a stainless steel dust recycling facility to meet both market demands and commitments to SAMANCOR and Columbus to treat their stockpiles and current dust arisings.

This paper describes the development work at Mintek on the processing of stainless steel dusts from Columbus Stainless using the Enviroplas technology and touches briefly on the application by Mogale Alloys to produce a nickel chromium alloy, and on other commercial application feasibility studies.

2. Developments on the Enviroplas Technology at Mintek

The Enviroplas™ process[1] [2][3] was developed at Mintek for the treatment of solid wastes from the metallurgical industry and is a DC arc process that can treat EAF dust, alloy-steel dust, or a mixture of both. The process is based on the reduction of selected metal oxides at high temperatures by means of a carbonaceous reducing agent, with the production of an innocuous slag. The main objectives of the Enviroplas process are to produce disposable slag and in the case where dust from a stainless-steel operation (e.g. AOD dust) is smelted, another objective is to recover chromium and nickel into a crude ferroalloy.

The advantages of Enviroplas Process hinge primarily around the DC arc furnace as follows:

- The operation is open bath which negates the necessity for costly agglomeration of fines
- Kinetics of the process are fast such that the results and high recoveries are closer to thermodynamic prediction as a result of even temperature distribution and improved slag/reductant contact.
- Tighter control of the reagent mix and power results in optimized chemistry with greater flexibility.

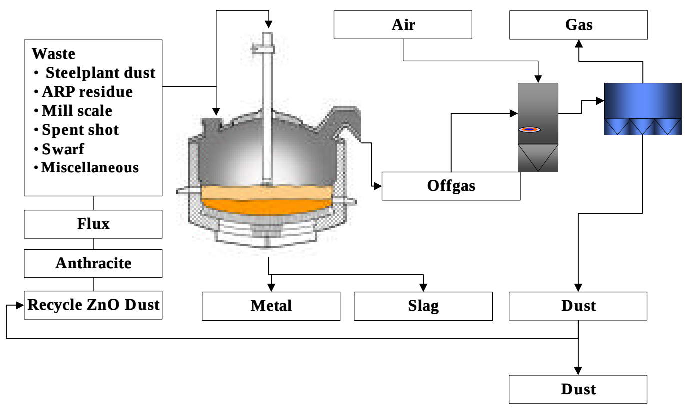

Fig. 1: Typical Process Flowsheet for Stainless Steel Plant Waste Processing

2.1 PILOT SCALE Treatment of Steel Plant Dust

The suitability of the Enviroplas process for the smelting of zinc-bearing alloy-steel dust was first demonstrated at Mintek in 1990, during a 5-day continuous campaign on the 500kW scale of operation. In 1995 a 3-day campaign was carried out on the smelting of alloy-steel dust in Mintek's 5.6MVA DC arc facility. The results of this testwork are described elsewhere. [4][5]

This was followed by further testwork of which the most recent was a 5-month campaign involving the smelting of 1700t of Columbus Dust on Mintek's 5.6MVA DC arc furnace. Batches of 3t were continuously fed to the furnace and slag was tapped after every 2-3 hours. The reductant-to-dust ratio in the feed was selected to reduce the iron, chromium, nickel, lead and zinc oxides in the dust to their respective metals. Metal was tapped after these batches, typically after 9t had been fed to the furnace. Combustion air is drawn in to burn the zinc, and lead through a slip gap and a mixed oxide of zinc, lead and entrained dust were recovered in the bagfilter.

2.1.1 Description of the Pilot Plant

The equipment consisted of a raw material feed system, DC arc furnace, gas cleaning system and instrumentation for data logging and control. The arrangement was similar to that presented in Figure 1 with the exception that solids captured from the offgas stream were not recycled back to the furnace.

The feed system consisted of three hoppers, one each for reductant, flux and dust, mounted on loadcells and fitted with independently controlled beltfeeders. The dust feeder consisted of a $2m^3$ hopper equipped with two vibrators in its conical section.

The DC arc furnace comprised a refractory-lined cylindrical shell (3m diameter) and conical roof, with a central graphite electrode connected to a 5.6MVA thyristor based DC power supply. The roof and top section of the shell was equipped with forced water-cooling while in the middle section spray/film cooling was used. Both the feed and offgas ports were located in the roof. The off-gas system comprised of water-cooled ducting, a combustion chamber, a reverse pulse bag filter, a fan and a stack.

Overall a Distribution Control System (DCS) provided a console for the configuration of operating parameters, recipe management, alarm communication and data logging.

The furnace was operated at power levels of between 0.8 and 1.6MW on a 24-hour basis and feed was supplied to the furnace at a constant rate (typically between 0.5 and 1 ton/hr of dust).

2.1.2 Feed materials and Products

Overall a reductant addition of 24.2 per cent of the feed dust, was utilised. The reductant comprised of anthracite coal (82% fixed carbon, 14% ash and 6.8% volatiles). Small amounts (2-4%) of magnesite or dolime was occasionally added to the smelting recipe to aid bank formation. Flux addition was commenced/ceased under following conditions:

- Commenced if the energy flux through the furnace middle section area seen to increase.
- Ceased as soon as the bank thickness was deemed to be satisfactory.

The average chemical analysis of the Steel Plant Dust processed and emanating products are shown in Tables 1 and 2.

Table 1: Average Chemical Analyses of the Steel Plant Dust, Slag and Fume (all in mass %)

Material	Cr_2O_3	FeO	ZnO	NiO	MnO	SiO_2	CaO	MgO	Al_2O_3	PbO
Feed Dust	13.45	42.52	4.94	3.79	4.38	5.61	12.53	4.19	0.80	0.59
Slag	1.46	2.23	0.03	0.20	2.46	24.5	45.3	14.9	4.96	0.009
Fume	2.71	10.7	34.4	1.34	5.98	4.30	5.29	12.7	0.88	4.12

Table 2: Average Chemical analyses of the Alloy (all in mass %)

Cr	Fe	Mn	Ni	C	Si
17.7	63.7	4.52	5.86	5.37	0.22

Phosphorous and sulphur, i.e. important elements with regard to recycling, were analysed in the alloy at 0.019 and 0.008 per cent respectively. Because of the relatively small quantities involved, no problems are envisaged with regard to contamination when the ferroalloy is recycled to steelmaking furnaces. The fume was contaminated on average with around 1 per cent each of Cl, F, Na, and K. Low concentrations of As (30 ppm) was also encountered. The disposal of the fume from the DC furnace or recovery of zinc and other elements is an important issue. Mintek disposed of the fume in a class I site because the quantity was small. However various options need to be considered for commercial scale plants depending on the location, availability and costs of disposal sites and liabilities. The recycling of the fume to enrich the zinc content and increase e.g. nickel recovery is one approach. The pre-treatment of the fume to recover the metals by (e.g. washing the halides) and making the residue more saleable has been evaluated but falls outside the scope of this paper.

Steel Plant Dust (feed), slag and fume samples were submitted for toxicity leaching tests of which the product slag was found to conform to US EPA regulations for disposal (Table 3).

Table 3: TCLP tests for dust, slag and fume (all in ppm)

	Cr^{6+}	F	Cr	Mn	As	Cd	Hg	Pb
Feed Dust	6.25	1.84	5.7	0.04	<0.01	<0.01	<0.01	0.05
Slag	<0.02	1.85	<0.02	0.04	<0.02	<0.01	<0.01	0.05
Fume	0.48	1.89	0.47	21	0.01	2.6	0.01	0.13
TLCP Max.	2	-	5	3	5	1	0.2	5

2.1.3 *Energy Balance and Electrode consumption*

The energy consumption excluding energy losses was 1.36 MWh/ton dust while the overall energy consumption for the smelting of feed dust with anthracite (including 70% thermal efficiency and plant availability) was 2.07 MWh/ton dust. Expressed as a percentage of the power input the rate of energy loss is expected to decrease when the process is scaled up, as experienced during other processes tested at Mintek. It is envisaged that a 10MW industrial plant would have a thermal efficiency of about 85 per cent.

The slag temperature varied between 1625°C and 1750°C with an average temperature of 1687°C. For the metal, the temperature varied between 1350°C and 1600°C with an average temperature of 1459°C. Electrode consumption was calculated and varied between 3.15 to 3.51kg/MWh. During steady state operation a 90kg electrode section was added once per day. Here again electrode consumption is expected to decrease when the process is scaled up.

2.1.4 *Mass Balance and Recoveries*

Approximately 1655t of Steel Plant Dust, 400t of anthracite and 15t of flux were fed to the furnace. In total, about 792t of crude ferroalloy, 329t of slag and 166t of baghouse fume (8% of total feed) were produced during the campaign. The deficit can mainly be attributed to the formation of CO gas during the reduction of the iron and chromium oxides.

Recoveries of chromium and nickel to the metal were calculated and amounted to 92 and 94 per cent, respectively on a once through basis i.e. no baghouse fume recycled (Table 4).

Table 4: Recoveries of Nickel and Chromium

	Metal %	Slag %	Fume %	Total %
Cr	92.0	2.2	2.0	96.2
Ni	94.2	1.0	3.5	98.7

2.1.5 *Equipment Performance*

In general bagfilter dusts are problematic materials to transport and feed. Considering this, the DC furnace performed well with high availability due to only occasional minor feed blockages being experienced.

As mentioned previously, magnesite or dolime were used to promote bank formation in the furnace, thereby protecting the furnace refractories. The flux addition was ceased as soon as the banks were deemed to be satisfactory and added to the recipe if the energy flux through the furnace middle section area (vertical band corresponding to the slag/metal interface) started to increase.

3. Mogale Alloys Operation

Mogale Alloys is a consortium of Mindev (a wholly-owned subsidiary of Mintek) with a 25 per cent shareholding, Apic Toll Treatment (Atoll), a Mintek/Bateman joint venture (20 per cent), PGR Investments 17 (25 per cent), and Sebeso (30 per cent, including 10 per cent held by former employees via a Trust). The plant is managed and run by former staff operating as PGR, with technical input from, Mintek, Sebeso and Atoll/Bateman. The operation represents the latest application of the DC transferred arc smelting technology that has been developed by Mintek, with the support of industry and South Africa's Department of Science and Technology, for a variety of applications over the past 20 years. The venture, situated at Samancor's former Palmiet Ferrochrome plant near Krugersdorp, west of Johannesburg, uses a 40 MVA DC transferred-arc furnace to smelt stainless steel plant dust and other waste materials, recovering valuable metals into a ferronickel-chromium master alloy for recycling to the stainless steelmaking process. Mogale Alloys also has two 20 MVA submerged-arc furnaces that can be used for the production of ferrochromium and silicomanganese.

The DC arc furnace at Palmiet, the first in the world to be used for ferrochromium production, was commissioned in 1983. Initially a 16 MVA unit, the furnace was uprated to 40 MVA in 1988, making it then the world's largest DC smelting furnace. DC technology allowed the production of special grades of ferrochromium (low-impurity), as well as the use of cheaper raw materials. The furnace continued to operate until the end of 2001, when Samancor decided to mothball the facility owing to market conditions.

In 2002, the Mogale consortium entered into an agreement with Samancor to lease the furnace and related infrastructure. The furnace was re-commissioned in March 2003, and is currently processing about 40 kt of stainless steel dust and wastes per year, for an alloy production of some 40 kt. per year. To fully utilise the furnace, Mogale has also produced limited quantities of ferrochromium from chromite supplied by Samancor on a toll-conversion 'swing production' basis.

On 28 February 2005 Mogale Alloys concluded the process of purchasing the Palmiet facility from Samancor. Mogale is now an independent producer with the flexibility to swing between waste processing and ferroalloy production as dictated by market forces.

3.1 Process outline

The technology employs the DC open-arc process to selectively reduce the metal oxides and recover the metals into an alloy phase for recycling. This is both an environmentally responsible and an economically viable approach, since the value of the metals exceeds the processing costs. About 92 per cent of the chromium and 96 per cent of the nickel are recovered into the alloy. The slag is well within the US Environmental Protection Agency (EPA) requirements for disposal at sites for non-hazardous waste.

The feed, consisting of a mixture of stainless steel plant dust, is partially dried and pelletized before feeding to the DC furnace together with chromite fines when required. The furnace is operated at power levels of 25-30 MW. Low volatile coal or anthracite is used as reductant. The alloy, which contains chromium and nickel (balance iron, carbon and silicon) is cast, and the product sold largely to Columbus Stainless. The slag is crushed, passed though a metal recovery plant, and disposed of in the usual manner - from time to time, quantities are sold as aggregate.

The plant has operated on this basis for the past two years and is planning to continue with this type of operation for at least the next five to ten years. The flexibility allows the owners to adjust the alloy product produced from a 54% chromium- containing charge chrome to a 2% nickel – containing chromium alloy (with about 44% Cr). The latter allows the processing of about 40 to 60 kt/a of stainless steel dusts. This is sufficient to deplete both the stockpiles and current dusts being generated in South Africa and will support the regional environmental sustainability of the stainless steel industry.

The use of an existing 40 MVA DC arc furnace rather than build a new plant has given significant cost savings but also resulted in some operational constraints that could have been avoided on a new plant. Mogale Alloys has thus successfully implemented the treatment of the stainless steel dust processing and is continuing to improve the operation.

4. Commercial Application Feasibility Studies

Most stainless steel producers outsource the processing and/or disposal of EAF/AOD dusts and other wastes. Almost all stainless steel dust processing plants in Europe and the USA require economies of scale for viable operation and are situated at locations that may be far removed from some sources of dust. Few dedicated over-the-fence-processing facilities exist. However, due to increasing transport costs and environmental legislation relating to cross border traffic of wastes, several stainless steel producers have recently begun investigating on site processing of stainless steel dusts and other wastes.

The Enviroplas process is particularly well suited to on site processing because it is economically viable at relatively low throughput of dust and other wastes typical of plants producing e”500 000 tpa of stainless steel.

Atoll is a build, own, operate (BOO) entity that belongs to Mindev and Bateman. Mindev provides the process design for Enviroplas and Bateman the engineering design and project management for projects which Atoll finances, owns and operates. To date Atoll has provided BOO proposals for on site Enviroplas plants in Spain, Belgium, Finland as alternatives to existing remote processing services and in South Africa in response to a tender from Columbus Stainless. A typical flowsheet, CAD of the plant and operating data for a 30 000 tpa Enviroplas process are shown in Figures 2 & 3, respectively. A financial analysis of the process is presented in Table 5. This shows that for a typical austenitic stainless steel dust the value of the alloy recovered exceeds the cost of processing and Enviroplas is a profitable waste recycling option for on site dust and waste processing, especially at current Ni prices.

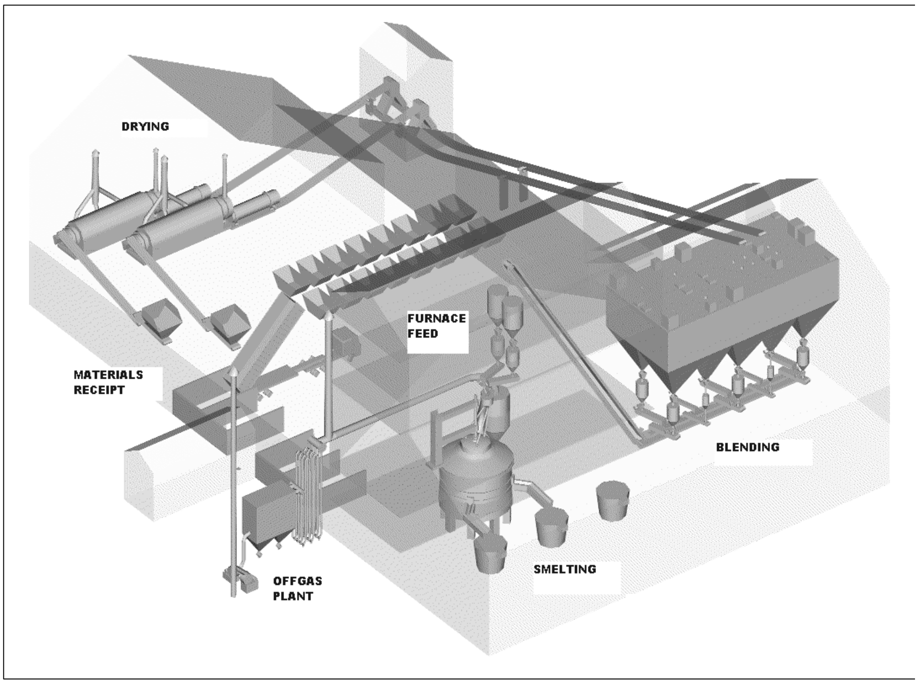

Fig. 2: Flowsheet for a 30 000 tpa Enviroplas process

Columbus Stainless benefits from the unique technology and economy of scale offered by the Mogale Alloys process. A few other stainless steel producers in the world could also do so. They are typically those who produce both ferrochromium and stainless steel on site i.e. Acesita in Timoteo, Brazil; Outokumpu Stainless in Tornio, Finland and potentially Oriol in Khazakstan.

Many stainless steel producers require a service to process Enviroplas recyclable wastes such as dust, mill scale, spent shot and acid pickling residues as well as neutralized acid pickling and polishing residues that are not suitable feeds for the Enviroplas process. At present most of these neutralization residues are disposed of the hazardous waste landfills. However, pickling effluents contain Ni in solution and Mintek is investigating methods of extracting the Ni before neutralization.

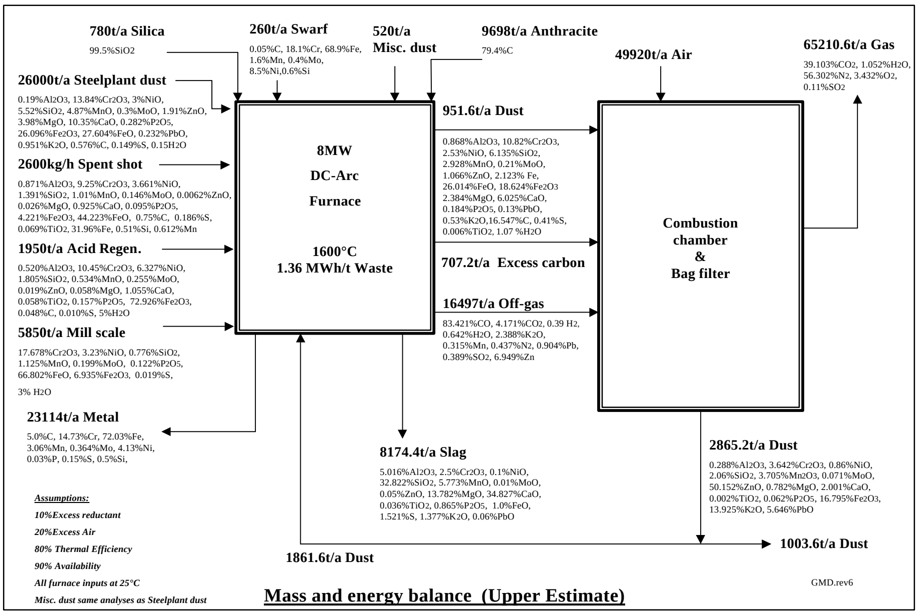

Fig. 3: Operating data for a 30 000 tpa Enviroplas process

Table 5: Enviroplas Financial Analysis

Processing Costs & Revenue

Feed Tonnage: 30 000 tpa, **Capital Cost:** U$ 15 000 000
Alloy Tonnage: 16 500 tpa, **Alloy grade:** 4%Ni, 16%Cr, 70%Fe

Operating Cost:

	U$ ('000)/a	U$/t
Variable Cost:	3 600	120
Fixed Cost	2 000	67
Capital Redemption:	2 000	67
Total	**7 600**	**354**

Revenue:	**U$ ('000)/a**	**U$/t**
Ni (95% of LME)	10 560	640
Cr (75% of CRU)	4 224	256
Fe (50% of LME)	825	50
Total	**15 609**	**946**

5. Conclusions

The suitability of a DC arc furnace for the smelting of alloy steel dust has been tested and demonstrated at Mintek for over a decade with the most recent work being the continuous processing of approximately 1700t of Columbus Steel Plant Dust over a 5 month period. An alloy containing around 18% chromium and 6% nickel was produced with high recoveries at 92 and 94 per cent, respectively. The overall energy consumption was 2 MWh / ton of dust with a thermal efficiency and availability of the furnace at 70 and 90 per cent, respectively. Furnace refractories were protected by the formation of banks along the sidewalls brought about by strict control of the power to feed ratio and the occasional addition of MgO containing materials during regimes of low slag liquidus operation. TCLP tests were carried out on the slags produced and these were found to be disposable according to EPA regulations. This campaign provided the confidence and ultimately led to the implementation of dust processing technology at Mogale Alloys in Krugersdorp, South Africa. Mogale Alloys has been in commercial operation for over two years during which time over 25kt of stainless steel dust has been processed. The primary product during the operation has been ferrochromium with the nickel chromium iron ferroalloy as a secondary product. The future plan is to increase the amount of dust to be processed and produce the nickel chromium iron alloy as the major product (subject in part to market conditions) and commitments to treat the stockpiles of dust and current arising. Mogale Alloys has become a successful business that provides a long-term solution to the treatment of dusts from the South African Stainless Steel producer, Columbus Stainless.

6. Acknowledgements

The paper is published with the permission of Mintek, Mogale Alloys, Atoll and Bateman.

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