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DC arc smelting of difficult PGM-containing feed materials

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Conventional PGM matte smelting requires the presence of a certain quantity of base metal sulphides in order to collect the platinum group metals in a molten sulphidic matte phase in the furnace. Furthermore, the quantity of chromium oxide in the feed materials is controlled in order to avoid the build-up of high-melting chromite spinels in the furnace.

Mintek has developed a process for smelting difficult PGM-containing feed materials that contain low amounts of sulphur and/or high amounts of chromium oxide. A DC arc furnace is used to provide the appropriate conditions to generate an iron alloy that collects PGMs very effectively, leaving extremely low residual quantities of PGMs in the slag.

Various feed materials have been treated successfully in furnace campaigns running at power levels up to 1.5 MW. The longest of these campaigns was run continuously for more than four months, treating more than two thousand tons of materials such as low-grade concentrates, revert tailings, and converter slag. The campaigns demonstrated the robustness and versatility of the process, and proved that it is possible to sustainably produce a PGM-containing alloy and discardable slags containing an average of less than 1.4 g/t of PGMs over the entire campaign.

Keywords: DC arc, smelting, furnace, platinum, PGM, revert tailings, converter slag, ConRoast

Introduction

Conventional PGM matte smelting requires the presence of a certain quantity of base metal sulphides in order to collect the platinum group metals in a molten sulphidic matte phase in the furnace. Furthermore, the quantity of chromium oxide in the feed materials is controlled in order to avoid the build-up of high-melting chromite spinels in the furnace.

Mintek has developed an alternative smelting process for the production of platinum group metals (PGMs).[1,2] Instead of the conventional matte smelting process, the ConRoast process is based on alloy smelting of dead-roasted sulphide concentrates in a DC arc furnace. The ConRoast process offers advantages in terms of being able to contain SO_2 emissions (by removing essentially all of the sulphur in a continuous enclosed roaster upfront of the smelting) and being able to accommodate a wide variety of feed compositions. There is no constraint on the minimum quantity of base metal sulphides required in the feed material, as the collection of the PGMs is done in an iron-based alloy. DC arc furnaces have been used industrially over the past two decades for such applications as the smelting of chromite[3], which demonstrates the ability of these furnaces to deal with high levels of chromite in the feed.

The ConRoast process has previously been piloted on a significant scale, on furnace campaigns treating up to 30 tons of feed material at a time. However, larger-scale demonstration of the process would be very expensive because of the requirement for large-scale production of dead-roasted concentrate. Fortunately, there are alternative feed materials that are sufficiently similar that they can be used for extended large-scale demonstration of DC arc smelting in the production of PGMs. These materials include medium-grade concentrates that are very high in chromite content and low in sulphur, as well as tailings from a milling-flotation process for the treatment of revert materials from an existing smelter.

Mintek has developed a process for smelting a wide variety of difficult feed materials that contain low amounts of sulphur and/or high amounts of chromium oxide. A DC arc furnace is used to provide the appropriate conditions to generate an iron alloy that collects PGMs very effectively, leaving extremely low residual quantities of PGMs in the slag.

Integration of PGM-containing iron alloy into an existing process

The product from the reductive smelting process taking place in the DC arc furnace is an iron-based alloy that contains substantially all of the base metals and PGMs that were present in the feed. The full implementation of the ConRoast process allows for the possibility of hydrometallurgical refining of the alloy (including an iron-removal step). However, for immediate industrial-scale implementation, it is more practical to integrate the relatively large quantities of the alloy product into an existing smelter, possibly through a converter. As the alloy makes up a small fraction of the total feed, the effect on the existing smelting process will be small.

Economic benefit of demonstration-scale testwork

Large-scale testwork on furnaces is very expensive, but is widely acknowledged as being necessary because of the risk of failure of new smelting operations if they are not properly understood. However, if the scale of the work is large enough, it is possible to make the testwork pay for itself (or even to generate a profit for the client) by utilizing the products from the furnace. Recovery of the contained metals is a significant economic incentive for treating waste materials.

Environmental benefits of demonstration-scale testwork

It is possible to treat all of the material contained in a medium-sized dump over a period of a few years, by running a pilot furnace at a power level of 1–2 MW. Remediation of tailings dams or other dumps removes the possibility of environmental damage by airborne dust or by leaching of the contained heavy metals into the groundwater. The slag generated by this process in the DC arc furnace conforms to US EPA requirements for safe disposal into a landfill site. Furthermore, the clearing of dumps makes valuable land available for more productive purposes. Another long-term benefit may be obtained by the demonstration of the sustainability of this processing method, thereby providing sufficient confidence to allow the adoption of a much more environmentally friendly smelting process to replace the ageing matte-smelting process. This could have a very significant beneficial impact on the levels of SO_2 emissions along the Bushveld Complex.

Feed materials

A number of feed materials have been tested to establish their suitability for the process. A medium-grade UG2 concentrate (high in chromium, and low in base metal sulphides) was found to work very well indeed when mixed with a small quantity of converter slag (as a source of supplementary iron collector). Smelter concentrate sweepings, even though they have a high sulphur content, also worked well when mixed with varying proportions of converter slag. High recoveries of PGMs were obtained from converter slag, but the grade of the resulting alloy was rather low, as very reducing conditions were used to produce a large quantity of alloy in order to avoid the formation of aggressive furnace slags with a high FeO content. The primary focus of the work has been on the treatment of revert tailings (the waste from a milling-flotation process for the treatment of revert materials from an existing smelter), and more of this material has been treated than any other.

The weighted average compositions of the feed materials are presented in Table I.

Drying of revert tailings

The revert tailings have a clay-like consistency when recovered from the tailings dams. The weighted average moisture content of the delivered material was approximately 19%. After being delivered by bulk side-tipping trucks, the material is loaded by front-end loader into a feed hopper, which discharges onto a conveyor belt that feeds an electrically-heated rotary kiln that operates at a temperature of up to 550ºC. Moisture is removed as steam from the revert tailings, in order to lower the moisture level of the product to approximately 2 per cent (which is the desirable level for feeding to the furnace). The kiln is able to produce over 30 tons per day of bagged dried revert tailings. Any dust that leaves the kiln together with the steam is captured in a dust scrubber, and the resulting sludge is allowed to settle before being returned to the stockpile of wet material for reprocessing.

Furnace operation

The bottom-opening bags of feed material are introduced into the furnace feed hoppers by crane. The hoppers are equipped with vibrators to provide for the smooth discharge of the feed material onto belts that deliver the feed into a conical funnel and feed pipe situated in the furnace roof. The furnace used comprises a refractory-lined cylindrical steel shell with an outside diameter of 3 m. The furnace has separate tapholes for the removal of alloy and slag. The furnace is fed more or less continuously, and is tapped intermittently. A single solid graphite electrode is used as the cathode, and the anode at the bottom of the furnace is made up of a number of steel pins that protrude through the refractory hearth to come into intimate contact with the molten alloy. The gas that leaves the furnace passes through a baghouse to remove the entrained dust (for reprocessing) before being treated in an SO_2 scrubber prior to discharge through a stack.

The particular furnace used in the work reported here is equipped only with film water cooling on the sidewalls. This places some constraints on the intensity of the operation, and on the level of aggressiveness of the slag that needs to be contained in the vessel. The furnace was generally operated with slag temperatures between 1550 and 1600ºC, and metal temperatures about a hundred degrees cooler than this. Anthracite (with a fixed carbon content of about 74%) was used as the reducing agent for the process, and, for the most part, no flux was added to the furnace. There was an occasional addition of high-magnesia slag additives (crushed bricks, etc.) to supplement the formation of a freeze lining on the sidewalls. A high-melting spinel is present in the slag (at the level of a few per cent), and this assists in the formation of a protective layer of solidified material on the sidewalls. The tapholes performed well, with only two replacements of the alloy taphole lining being required over a four-month period. Energy is lost from the shell of the furnace at a rate of up to 450 kW when the furnace is operating at its higher temperatures and power levels. The temperature distribution in the furnace was responsive to such factors as arc length and the state of the upper surface of the molten bath; this allowed the furnace to be well controlled. The furnace slag is highly resistive, which results in relatively high-voltage operation.

The operation of the furnace has been characterized by the production of very clean (barren) slags much of the time. No appreciable entrainment of alloy in slag was encountered. PGM contents less than the 0.28 g/t detection limit have been common, and the weighted average PGM

Table I
Composition of feed materials, mass %

Feed material	Al_2O_3	C	CaO	Co	Cr_2O_3	Cu	FeO	MgO	Ni	S	SiO_2	H_2O	Total
Revert tailings	3.7	0.2	6.0	0.18	2.6	0.3	34.7	10.1	0.99	0.85	34.2	2.5	96.3
UG2 conc.	5.0	0.2	2.9	0.03	4.9	0.2	13.0	22.6	0.44	0.86	44.4	-	94.6
Smelter conc.	3.5	0.4	4.1	0.12	2.0	1.8	22.0	14.3	3.07	7.2	33.5	-	92.1
Converter slag	1.4	0.2	1.9	0.30	2.7	0.8	55.1	3.7	1.51	1.7	30.0	-	99.1

content in slag over the first two months of the campaign was 0.8 g/t. After this, there was a deliberate attempt to operate the furnace under slightly less reducing conditions in order to produce less alloy (therefore higher grade) than was done initially. During the smelting of revert tailings to date, the quantity of alloy produced was equivalent to 11% of the mass of the dried revert tailings fed to the furnace (i.e. about 9% of the mass of the revert tailings as delivered). The maximum daily throughput was 30.5 tons of dried revert tailings. Typical feed rates were around one ton per hour. Very high recoveries of PGMs were obtained.

Some aspects of the furnace operation are summarized in Table II. The anthracite addition, and the quantity of alloy, slag, and dust produced are all expressed relative to the mass of the PGM-containing feed material, as are the specific energy requirement of the process (excluding losses from the furnace shell) and the electrode consumption. (Note that, because of the addition of slag additives during the converter-slag-only operation, the percentages of the alloy, slag, and dust total more than 100% when expressed relative to the converter slag fed to the furnace.)

UG2 concentrate was processed together with a small quantity of converter slag (in a 75:25 ratio by mass). It should be noted that this generates slags very similar in composition to those produced when smelting revert tailings. Smelter concentrate sweepings were also treated in varying ratios together with converter slag, culminating with the treatment of converter slag on its own. Because of the non copper-cooled furnace, a conservative mode of operation dictated that the FeO content of the slag be kept to moderate levels, and this required very strongly reducing conditions when smelting only converter slag. This resulted in too much alloy being produced, and so was not found to be an ideal candidate for this process (except perhaps if run under much less reducing conditions in a copper-cooled furnace). Revert tailings were treated on their own. The weighted compositions of the slags produced in the various modes of operation are listed in Table III. The PGM content was analysed by fire assay, and so represents the approximate total of Pt + Pd + Rh + Au. The average slag tapping temperatures for the various conditions are 1559, 1587, 1530, 1509, 1517, and 1554ºC respectively. The weighted compositions of the alloy produced during the various periods are listed in Table IV, but these are more susceptible to variation, as the amount of alloy produced is small relative to the amount inside the furnace at any time. Note that there wasn't yet sufficient alloy produced to be able to tap during the treatment of the UG2 concentrate, so no alloy composition is reported for this period (although it would be expected to be similar to the alloy produced from revert tailings).

Table II
Summary of some aspects of the furnace operation, under various conditions

PGM-containing feed	Tons processed	% Anthracite	% Alloy	% Slag	% Dust	MWh/ton	Electrode kg/ton
75% UG2 conc. + 25% converter slag	18	4.8	22	60	4.6	0.61	2.9
75% Concentrate + 25% converter slag	34	3.5				0.53	
50% Concentrate + 50% converter slag	72	7.6				0.60	
25% Concentrate + 75% converter slag	30	7.9				0.65	
Converter slag	279	10.8	28	77	2.4	0.76	1.7
Revert tailings	>1500	5.0	11	77	4.7	0.70	2.3

Table III
Slag composition, mass % (PGM listed in g/t for Pt + Pd + Rh + Au)

Material treated	Al_2O_3	CaO	Co	Cr_2O_3	Cu	FeO *	MgO	Ni	S	SiO_2	PGM	Total
75% UG2 conc. + 25% converter slag	4.5	4.4	0.03	4.2	0.07	21.1	20.2	0.11	0.26	43.3	0.6	98.1
75% Concentrate + 25% converter slag	4.2	5.3	0.06	2.7	0.14	25.4	15.6	0.18	0.51	43.6	0.9	97.7
50% Concentrate + 50% converter slag	4.2	5.3	0.03	3.7	0.10	21.8	13.2	0.05	0.47	48.6	0.6	97.6
25% Concentrate + 75% converter slag	3.5	4.2	0.04	3.8	0.13	29.6	9.6	0.06	0.57	48.6	0.6	100.1
Converter slag	3.5	2.6	0.04	5.1	0.13	33.5	12.8	0.03	0.57	41.0	0.6	99.4
Revert tailings	4.9	7.4	0.04	3.1	0.07	28.0	12.7	0.10	0.34	43.3	1.6	100.1

* Total Fe expressed as FeO

Table IV
Alloy composition, mass %

Material treated	C	Co	Cr	Cu	Fe	Ni	S	Si	Total
75% Concentrate + 25% converter slag	0.03	0.66	0.20	6.9	61.9	10.3	18.5	0.16	98.7
50% Concentrate + 50% converter slag	0.09	0.74	0.82	4.8	71.4	8.6	12.1	0.10	98.7
25% Concentrate + 75% converter slag	0.05	0.79	0.35	4.6	73.8	11.8	11.8	0.02	99.2
Converter slag	0.12	0.96	0.31	3.0	86.2	5.3	4.6	0.16	100.7
Revert tailings	0.12	1.21	0.21	2.1	83.7	8.0	3.7	0.51	99.6

Table V
Recoveries of elements to the alloy, % of feed

<table>
<tr><th>Material treated</th><th>Co</th><th>Cr</th><th>Cu</th><th>Fe</th><th>Ni</th><th>S</th><th>S to gas</th></tr>
<tr><td>75% UG2 Conc. + 25% converter slag</td><td>85</td><td>-</td><td>89</td><td>50</td><td>91</td><td rowspan="4">68</td><td rowspan="4">25</td></tr>
<tr><td>75% Concentrate + 25% converter slag</td><td>70</td><td>2.2</td><td>91</td><td>40</td><td>93</td></tr>
<tr><td>50% Concentrate + 50% converter slag</td><td>92</td><td>13.0</td><td>96</td><td>66</td><td>99</td></tr>
<tr><td>25% Concentrate + 75% converter slag</td><td>92</td><td>6.9</td><td>95</td><td>63</td><td>99</td></tr>
<tr><td>Converter slag</td><td>90</td><td>2.8</td><td>88</td><td>53</td><td>98</td><td>59</td><td>18</td></tr>
<tr><td>Revert tailings</td><td>81</td><td>1.4</td><td>81</td><td>36</td><td>92</td><td>47</td><td>23</td></tr>
</table>

Of principal interest in a metal recovery process is the deportment of the various elements to the alloy phase. In the furnace campaign described here, the dust that is produced from the furnace and captured in the baghouse is all recycled back to the furnace. On that basis, as long as the elemental accountability is good, the simplest expression of recovery of a given element is the ratio between the mass of its content in the alloy divided by the combined mass of its content in the alloy and slag. Sulphur has to be treated differently, as we are also interested in how much reports to the gas. The recoveries of various elements of interest are listed in Table V. (Note that the recoveries reported for the first condition—treating UG2 concentrate—had to be estimated on the basis of feed and slag, rather than alloy and slag, as there was no alloy tapped at that stage.)

Conclusions

A large-scale demonstration has been carried out over a period of more than four months, showing the viability of a DC arc smelting process for the treatment of difficult PGM-containing feed materials. The smelting process has been shown to be sufficiently robust for industrial application. The collection of PGMs in an iron alloy is efficient, and this provides grounds for confidence in the ConRoast smelting process.

Large-scale demonstration testwork can be economically favourable, in that it is possible to generate sufficient product that the work can pay for itself or perhaps even be profitable.

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