Zinc in South Africa*

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SYNOPSIS

The paper opens with brief descriptions of the history, occurrence, and regional geology of South African zinc deposits, and follows with descriptions of the resources, mining methods, and processes for the concentration of the sulphide minerals and the extraction of zinc as practised in South Africa. The end uses in the form of alloys or as salts are given in some detail. Statistics on the production and consumption of zinc in South Africa are given, and the current market situation and future prospects are discussed briefly.

INTRODUCTION

The origin of the name zinc is obscure, but it is believed that the word originated from the German word meaning point, jagged part, or tooth. This term could have applied to the appearance of the ore, as well as to any hexagonal crystals of zinc as produced in a furnace. Elemental zinc is bluish-white and lustrous, and is brittle at ordinary temperatures but malleable at 100 to 150 °C. The metal melts at 419,5 °C and boils at 907 °C. The distribution in nature of the five stable isotopes of zinc is as follows:

- Zn64: 48,89%
- Zn66: 27,81%
- Zn67: 4,11%
- Zn68: 18,57%
- Zn70: 0,62%

The most significant chemical property of zinc is its high reduction potential, which is responsible for its extensive use in coatings on steel and as a sacrificial anode in protecting pipelines and ships’ hulls. Zinc oxide has useful chemical, electronic, optical, and thermal characteristics, and various grades are therefore marketed. In alloyed form, it can be cast in fine detail into complicated shapes. However, as an industrial material, it has the disadvantages of poor creep resistance and low strength-to-weight ratio compared with those of other materials.

In nature zinc occurs mainly as a sulphide mineral usually associated with lead, iron, and copper sulphides. The mining of zinc can be regarded as conventional, and the sulphide mineral is readily separated by flotation.

It is generally accepted that zinc is not an easy metal to produce from its mineral concentrates, and the concentrate is normally converted to zinc oxide before being reduced to the metal. Reduction can be achieved via hydrometallurgical or pyrometallurgical routes.

The annual world consumption of zinc metal is approximately 7,1 million tons, of which South Africa uses approximately 87 000 tons.

HISTORY

The exploration for mineral deposits and their mining antedate metallurgical processes since the first metals used by man, namely gold and copper, were exploited in their native (elemental) state and were found on or near the earth’s surface. The visible ‘massive’ ore needed only hand trimming before being worked into shape.

The Greeks of the Hellenistic era were the first to identify and describe a mineral deposit containing zinc—that at Laurion—but lacked the technology to extract the zinc from the crystals of zinc carbonate. In Roman times it became accepted practice to heat metals in a furnace and, as copper was a sought-after metal, its ores were often smelted. When the copper ore contained a zinc component, as occurred in the copper deposits of northern Europe and Asia Minor, the smelting process produced a metal alloy, which is now commonly termed brass. The first smelter production of zinc metal was described by the Roman writer Strabo in about 200 BC. He wrote of an ore from Andeirae in Asia Minor that, when burnt, became iron and then, when heated in a furnace with a ‘white earth’, distilled ‘mock silver’.

Zinc smelting on a production scale is considered to have originated in China, where the making of malleable zinc is known to have been practised in the seventh century AD. In India, zinc was produced before 1380 from ore mined at Zaivar. By the seventeenth century, zinc was being imported into Europe from Asia, and in 1743 a zinc smelter for the treatment of zinc oxide was erected in Bristol, England. In 1758 an Englishman, John Champion, was granted a patent on the roasting of zinc sulphide to produce zinc and, by the early nineteenth cen-

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tury, zinc smelting was well established in Germany and Belgium.

**Zinc Deposits and World Resources**

Zinc ores are widely distributed throughout the continents, the sulphide mineral sphalerite providing almost 90 per cent of the zinc metal produced. The other zinc minerals, which are often associated with sphalerite, i.e. zincite (ZnO), smithsonite (ZnCO₃), zincoxide (ZnSO₄), franklinite (Fe, Zn, Mn) O (Fe, Mn)₂O₃, and willemite (Zn₂SiO₄), make up the remainder of the production. Most zinc ores also contain economically recoverable quantities of lead, copper, silver, gold, and barium. Trace metals associated with sphalerite concentrates include silver, cadmium, germanium, gallium, indium, and thallium.

Most exploitable primary zinc ores can be divided into five principal categories based on differences in their geological occurrence:

(a) volcanic-hosted submarine exhalative massive sulphide deposits such as the Japanese Kuroko deposit,
(b) sediment-hosted submarine exhalative deposits such as the Australian Mount Isa deposit,
(c) strata-bound carbonate-hosted deposits such as the American Mississippi Valley-type deposits,
(d) strata-bound sandstone-hosted deposits such as the Swedish Vassbo deposits, and
(e) vein-, replacement-, and contact-metasomatic deposits such as the American Bingham deposit.

The major economic and promising sub-economic resources of zinc in the world, according to Carr and Herz in 1989, are estimated at 266 Mt. These resources are located in Australia, the Americas (USA, Canada, Mexico, Peru) at 133 Mt, the USSR at 13 Mt, Africa at 21 Mt, Western Europe at 20 Mt, India at 12 Mt, Japan and China at 12 Mt, and others at 16 Mt. Currently, most zinc ores are mined by underground methods, but many of the newly discovered deposits are, or could be, worked as open cast mines.

An estimate of zinc resources made by Penarroya in 1983–84 and published in 1986 showed that the total world reserves could have a life of 46 years. The Western World has 89 per cent of future supplies, which could be sufficient for the next 56 years.

**South African Deposits and Reserves**

Up to two decades ago, it appeared that zinc was missing from South Africa’s mineral endowment, although numerous small, non-economic occurrences had been investigated. As a result, the country’s supplies of zinc had to be imported but, in the late 1960s, economically viable mixed-sulphide deposits were discovered in the northwestern Cape Province.

The South African zinc deposits currently mined in the northwestern and northern Cape Province are shown in Fig. 1 and are as follows:

- the zinc–copper orebody at Copperton (Prieska Copper Mine, No. 2), which started production in 1974 and ended production in 1991;
- the Broken Hill lead–zinc orebody at Aggeneys (Black Mountain Mineral Development Co., No. 1), which started production in 1979;
- the zinc orebody in the northern Cape Province (Perring Mine, No. 4), which started production in 1986.

These mining operations have made the Republic of South Africa self-sufficient in zinc.

The following zinc deposits have been evaluated but have not yet been mined:

- the Black Mountain and Big Syncline deposits, which are in close proximity to the Broken Hill orebody at Aggeneys;
- the extensive zinc deposit at Gamsberg, which is shown as No. 3 in Fig. 1;
- the zinc–copper orebody at Areachap, in the Gordonia district;
- the Bushy Park zinc–lead deposit, in the Griqualand West district.

The massive sulphide deposits of Broken Hill, Black Mountain, Big Syncline, and Gamsberg are all located in metasedimentary units of the Precambrian Bushmanland Sequence, which is preserved in the western portion of the extensive Namaqua Metamorphic Complex. They range in age from 1600 to 2000 million years. All these stratiform orebodies are hosted by the Aggeneys ore formation, which consists of a 200 m thick succession of pelitic schist interbedded in places with thin units of quartzite, calcite–sillicate rock, and banded ironstones. The subsequently deformed stratabound orebodies are considered to be sediment-hosted exhalative deposits consisting of varying concentrations of galena, sphalerite, and chalcopyrite that, together with pyrite, achieve massive sulphide proportions.

The Prieska and adjacent Areachap copper–zinc deposits are located in the metavolcanics and associated sediments of the Korannaland Sequence, which is preserved close to the eastern boundary of the Namaqualand Complex and the Kaapvaal Craton. The Prieska copper–zinc deposit has not been mined since the official closure of the mine in January 1991, whereas the Areachap deposit, because of its relatively small ore reserves, has never been exploited.

The abovementioned massive sulphide deposits, hosted by the Namaqualand Complex constitute the major...
source of South Africa's zinc concentrates, as can be seen from the listing of the country's zinc resources (Table I).

In contrast, the Pering zinc deposit is hosted by the early Proterozoic dolomitic sequence of the Transvaal Supergroup. Sphalerite and minor galena are the ore minerals, usually disseminated but sometimes crustiform, where they occur in sub-horizontal stratiform lenses and sub-vertical breccia zones. The mineralization is not considered to be syngentic but a secondary product of basinal dewatering. Another small zinc deposit exists in the dolomites of the Transvaal Supergroup at Bushy Park, some 100 km west of Kimberley, where a resource of 0.59 Mt grading 3.5 per cent zinc and 2.8 per cent lead occurs in breccia pipes.

SOUTH AFRICAN MINING OPERATIONS

Prieska Copper Mines

Prieska Copper Mines (Pty) Ltd was established in the late 1960s to mine the orebody of copper, zinc, and pyrite that lies 64 km southwest of Prieska in the northwestern Cape Province. Diamond drilling indicated the presence of 60 Mt of ore containing 30 per cent pyrite, 1.74 per cent copper, 3.87 per cent zinc, 8 g/t silver, and 0.4 g/t gold. The orebody was described as having a strike of 1800 m, with an average thickness of 10 m and extending to a depth of at least 900 m. The upper 85 m of the deposit has been altered by weathering. The orebody below the oxidized zone dips steeply and is almost vertical in places.

Fig. 2 is a diagrammatic sketch of the mine layout. Access to the orebody is from the hoisting shaft, which is 8.84 m in diameter, now 1024 m deep, and placed 350 m from the orebody and in the footwall. Haulage ways connect this shaft to the orebody. A spiral roadway from the surface measuring 3.7 m by 3.7 m in cross-section has also been installed in the footwall, between the shaft and the orebody.

Ore is mined by blasting from holes drilled parallel to the orebody from stripping crosscuts. Diesel-driven load-haul-dump (LHD) vehicles transport the ore from the stopes to tips supplying a tracked electric haulage system using 20 t bottom-discharge hoppers. This system delivers the rock to the main ore passes, which supply a 150 mm gyratory crusher. From here, the crushed rock is hoisted to the surface for further treatment.

Black Mountain

Exploration in the Aggeneys area started in 1929, when a prospecting shaft was sunk on Black Mountain. Thereafter, only superficial investigations were conducted until 1970, when Phelps Dodge Corporation started a diamond drilling programme.

Three orebodies (Black Mountain, Broken Hill, and Big Syncline) were identified during the period 1971 to 1973. In 1974 an adit was driven into the Broken Hill orebody for bulk sampling and metallurgical testing. The feasibility of openpit mining was examined initially, but in 1976 Phelps Dodge invited Bechtel to undertake a detailed study for underground mining. An area of 24 199 ha at Aggeneys was acquired by the Company. In 1977 Phelps Dodge reached an agreement with Gold Fields of South Africa Limited, who subscribed for a 51 per cent equity interest in the Black Mountain Mineral
Development Company (Pty) Limited and was to be responsible for the management of the company.

The Broken Hill deposit, because of its higher metal grade, was selected as the first orebody for mining, and mining operations started towards the end of 1979\textsuperscript{10}. Access to the orebody is via a spiral decline and a vertical shaft\textsuperscript{17,19}. Two underground mining methods were selected: blasthole stoping and cut-and-fill mining\textsuperscript{18,20}. Fig. 3 is a diagrammatic section through the mine, showing the access spiral decline, shaft arrangement, and limits of the blasthole stoping method in the steep sections of the orebody\textsuperscript{17}.

Blasthole stopes were developed in the upper section of the orebody, where the dip varied from 45 to 60 degrees\textsuperscript{19,20}. The blasthole stoping area is divided into primary stopes and pillar stopes\textsuperscript{20}. Extraction of the primary stopes is followed by backfilling with a mixture of classified sand, tailings, and cement. Extraction of the pillar stopes is followed by backfilling with sand. Fig. 4 shows a diagrammatic section of the blasthole stoping method that is used for the steep ore section\textsuperscript{17}.

At present all the ore is being mined by the cut-and-fill method, which was selected for the lower regions and the part of the orebody having a flatter dip. Horizontal slices 4 m thick are mined for a distance of 200 m on strike. The open space is then backfilled to within 1 m of the roof, and the sequence is repeated, the stope progressing up-dip\textsuperscript{19}. A 2,25 m layer of sand capped with a 0,75 m layer of classified mill tailings and cement in the ratio 10:1 is used as backfill (Fig. 5).

Pering Zinc–Lead Mine

The zinc–lead deposit at Pering is located 70 km southwest of Vryburg, in the northern Cape Province. This deposit was discovered by Shell South Africa Minerals Division in 1978, and exploration over the next 5 years proved a resource of 17 to 18 Mt at a combined grade of 4 per cent lead plus zinc. Mining started during 1986\textsuperscript{21}. Openpit methods are used to a depth of 90 m, and the mining and milling rate is approximately 22 kt per week. Blasthole drilling is carried to a bench height of 5 m, and blasting is conducted with a premixed explosive. The fragmented rock is removed from the mine by means of two hydraulic excavators and a fleet of five rear-dump trucks\textsuperscript{22}.

Concentration

The plant at Prieska Copper Mines produces copper and zinc concentrates; Black Mountain Minerals produces copper, lead, and zinc concentrates; and Pering produces lead and zinc concentrates.

Silver, when present, reports mainly to the lead concentrate and, to a lesser extent, to the copper concentrate. Where only copper and zinc concentrates are collected, the silver reports mainly with the copper but also with the zinc. Gold follows the silver\textsuperscript{23}.

Prieska Copper Mines

The concentrator at Prieska was designed to treat run-of-mine ore at the rate of 3 Mt per year for the production of 90 kt of copper concentrates containing 26 to 27
per cent copper, and 150 kt of zinc concentrates containing 52 to 54 per cent zinc\textsuperscript{16}. The design of the concentrator was based on several years of laboratory and pilot-plant investigation carried out during the late 1960s and early 1970s\textsuperscript{15,23}.

The ore is prepared for flotation as described by Beale\textsuperscript{15}, and the copper and zinc are floated sequentially. The zinc-flotation circuit is shown in Fig. 6\textsuperscript{24}.

**Black Mountain**

At Black Mountain, primary crushing to minus 150 mm is done underground, and the crushed ore is stored on the surface in five silos with a total capacity of 6 kt. The ore is crushed further to minus 16 mm, and is stored in five fine-ore silos having a total capacity of 6 kt\textsuperscript{19}. Open-circuit rod mills are used for milling, followed by ball milling in closed circuit with cyclones.

Flotation is carried out in sequence to collect sulphide concentrates of copper, lead, and zinc.

In the flotation of the copper and lead sulphides\textsuperscript{15,19}, the tailings from the lead flotation are conditioned with copper sulphate and with sodium ethyl xanthate, MIBC being used as frother. The rougher concentrate is put through a regrind mill prior to three stages of cleaning. The zinc-flotation circuit at Black Mountain is shown in Fig. 7.

The rougher flotation is carried out in 8 m\textsuperscript{3} Outokumpu cells, and 3 m\textsuperscript{3} Outokumpu cells are used for the cleaning stages. The tailings are pumped to a tailings dam. The zinc concentrate is shipped to Zincor in Springs for electrowinning of the zinc.

**Pering Zinc-Lead Mine**

The zinc-lead plant at Pering came on stream during the last quarter of 1986, and is producing a galena concentrate and a sphalerite concentrate containing about 55 per cent zinc\textsuperscript{21}. The particle size is reduced to approximately 100 per cent minus 90 \(\mu\)m by three-stage crushing followed by single-stage ball milling. The two concentrates are floated sequentially. Ore-blending facilities ensure steady head grades to the flotation circuit.

The zinc occurs in the form of sphalerite with an iron content of 0.55 per cent and a cadmium content of up to 0.28 per cent in the lattice. The gangue material is mainly dolomite, with minor quantities of pyrite, chalcopyrite, and carbonaceous shale. The zinc concentrate contains a significant concentration of magnesium, and has to be treated for the removal of magnesium before it is fed to the electrolytic-zinc plant.

**Gamsberg**

Laboratory and pilot-plant tests on the beneficiation of ore from the Gamsberg deposit showed an excellent response to flotation, and concentrates containing approximately 52 per cent zinc were produced.

A disadvantage of the Gamsberg zinc, if the electrolytic recovery route for zinc is to be followed, is the presence of manganese. As the pilot-plant flotation concentrates contained some 3 per cent manganese, treatment for the removal of manganese would be required.

**Production of Zinc Metal**

Metallic zinc has been marketed commercially for almost 200 years. During this period, great changes have taken place in the methods of extraction and also in the use of zinc in pure, alloyed, and compound forms\textsuperscript{5}. Table II shows the world production of zinc for the period 1800 to 1984, and the principal processes used.

The ease with which high-grade metal is produced directly in the electrolytic process gives it an advantage over its main competitor—the horizontal distillation process, which is being phased out (Fig. 8).
Tailings from copper flotation

80 × 3.2 m³ rougher flotation cells

To pyrite flotation

80 × 3.2 m³ scavenger flotation cells

16 × 1.4 m³ cleaner flotation cells

8 × 1.4 m³ recleaner flotation cells

8 × 1.4 m³ second-stage recleaner flotation cells

4 × 3 m³ final cleaner flotation cells

Fig. 6—Zinc-flotation circuit at Prieska copper mines

Tailings from lead flotation

7 × 8 m³ rougher flotation cells

2 × 20 m³ conditioners

4 × 8 m³ scavenger flotation cells

3-stage cleaning circuit
13 × 3 m³ flotation cells

Regrind mill 2.1 m × 3.3 m

Tailings dam

First cleaner

Second cleaner

Third cleaner

Mix-pump units

Thickening and filtration

Fig. 7—Zinc-flotation circuit at Black Mountain
The vertical-retort, Overpelt, blast furnace, and electrolytic processes were developed after 1930. Of these, the blast furnace has shown strong growth, whereas the other three methods have virtually disappeared from the scene (Fig. 9).

**Blast furnace Process**

In the 1940s, a new approach to the production of zinc and lead was made by the Imperial Smelting Corporation at Avonmouth, England, where the horizontal- and vertical-retort systems had been in operation since 1929 and 1933 respectively. The Corporation considered that, by using the blast furnace principle, a large unit could operate at low labour and maintenance costs and with higher thermal efficiency than was attainable by retorting methods. The difficult condensation problem that existed with the retorting method was overcome by C.J. Derham, who suggested the use of a spray of molten-lead droplets for rapid chilling and adsorption of the zinc vapour in the presence of high concentrations of carbon dioxide. In 1946 the first experimental blast furnace was constructed and brought into operation, and in 1950 the first prototype production furnace was commissioned.

Up to the end of 1984, the blast furnace process had operated 13 furnaces and had produced 11,9 Mt of zinc and 5,8 Mt of lead. This process now accounts for 12 per cent of the world’s zinc production. However, worldwide zinc is produced mainly by the electrolytic process and, in the Republic of South Africa, it is the only process in use.

**Electrolytic Process**

The electrolytic process was established industrially by Anaconda and Cominco (Canada) during the years 1914 to 1918 for the treatment of the complex zinc ores of North America. The metallurgists of Anaconda and Cominco made use of the basic principles already known, combined these with the best previously known methods and new discoveries, and adapted them to work commercially on a large scale. The main equipment (agitators, classifiers, thickeners, and filters) had already been developed previously for the cyanidation process and found immediate use in the hydrometallurgical treatment of zinc.

The success of electrolytic zinc production was due to an acknowledgement of the need to develop a satisfactory purification procedure for zinc sulphate solutions. During 1917, the Electrolytic Zinc Company of Australasia made a study of the North American process with a view to its adaptation to their cobalt-contaminated Broken Hill ore. This impurity caused serious dissolution of the plated zinc during electrolysis.

In 1922 a Norwegian engineer Robert Lepsoe delivered a paper entitled ‘On the conditions for electric production of zinc in Norway’. Lepsoe had seven years of practical experience in the electrothermic smelting of zinc, and had spent eight months studying zinc hydrometallurgy as used in North America. The Det Norski Zinc Kompani, which had tried the electrothermic method, decided in 1926 to change to the electrolytic method. The first electrolytic plant in Europe was erected at Eitrheim, Norway, under licence to the Anaconda Copper Mining Company, and it was a carbon copy of the Great Falls plant in the USA.

**Effect of Iron in the Electrolytic Process**

Iron in the concentrate lowers the dissolution of zinc during leaching because of the less-soluble zinc ferrite that is formed during roasting. This effect results in poor dissolution of the zinc since only the zinc oxide fraction dis-
solves during leaching. It was known that ferrites would dissolve in strong acid solution at temperatures close to boiling point, but the combined dissolution of iron and zinc in sulphuric acid led to the problem of separating these two metals. Much research work followed in attempts to precipitate the iron in a filterable form. Anaconda developed a special ‘Mechanical Acid Leach’ to dissolve the ferrites in the leach residue and to precipitate the iron as basic iron sulphates with calcite and ground lime-bearing rock. This method was practised at Great Falls and at Eitrheim, but was difficult to control. A method of residue treatment called red roasting, which, in fact, a sulphating roast, worked well, but the subsequent water leach to recover the zinc sulphate seriously affected the sulphate balance in the leaching circuit.

The breakthrough for the precipitation of iron in a filterable form came in 1964 with the discovery of a method to precipitate iron in the form of a jarosite. Other methods to precipitate iron from sulphate solutions soon followed and were put into practice.

Iron Precipitation in the Electrolytic Process

The following processes are used industrially to precipitate iron from zinc sulphate solutions: jarosite precipitation, goethite precipitation, the conversion process, hematite precipitation, basic iron sulphate precipitation, and direct leaching of the sulphide concentrate.

The precipitation of iron as a jarosite is carried out from a hot solution in the presence of sodium, potassium, or ammonium ions. The precipitate has good settling and filtration properties but, owing to its slow decomposition when placed on dumps, can cause water-pollution problems. When ammonium jarosite is precipitated, the reaction is as follows:

\[(NH_4)_2SO_4 + 3Fe_2(SO_4)_3 + 12 H_2O = 2NH_4Fe_3(SO_4)_2(OH)_6 + 6 H_2SO_4.\]

The goethite process was developed by Vielle Montagne of Belgium. The ferric sulphate dissolved during leaching with hot sulphuric acid is reduced with zinc sulphide to form ferrous sulphate, which is then oxidized with air or oxygen at a controlled pH value to precipitate the iron in the form of goethite. The precipitation of goethite can be described by the following equations:

\[2FeSO_4 + \frac{1}{2}O_2 + H_2SO_4 = Fe_2(SO_4)_3 + H_2O.\]
\[Fe_2(SO_4)_3 + 4H_2O = 2FeO.OH + 3 H_2SO_4.\]
\[2FeSO_4 + \frac{1}{2}O_2 + 3 H_2O = 2FeO.OH + 2 H_2SO_4.\]

In the conversion process, which was developed by Outokumpu Oy of Finland, the two steps comprising the jarosite process (i.e. leaching with hot sulphuric acid followed by liquid–solid separation and precipitation of the iron) are combined in that leaching of the zinc ferrite and precipitation of the dissolved iron as jarosite take place simultaneously. This process gives a better recovery of zinc than the jarosite process because no calcine is needed for pH control during the jarosite-precipitation stage. The combined reactions for this process proceed as follows:

\[3ZnFe_2O_4 + 6H_2SO_4 + Na_2SO_4 = 2NaFe_3(SO_4)_2(OH)_6 + 3ZnSO_4.\]

The hematite process was developed independently by the Dowa Mining Company of Japan, and by Ruhr-Zink of Germany. In this process, iron is precipitated predominantly as iron oxide (Fe₂O₃) in the presence of oxygen at approximately 180 °C and a total pressure of 1.8 to 2.0 MPa. The process can be described by the following chemical reactions:

\[2FeSO_4 + \frac{1}{2}O_2 + 2H_2O = Fe_2O_3 + 2H_2SO_4.\]

The process in which iron is precipitated as a basic sulphate was developed by Zincor in Springs (South Africa). This is a continuous process, being similar in this respect to the other precipitation methods. A slurry of zinc calcine in water and zinc sulphate solution also containing ferric sulphate are simultaneously added to a stirred vessel so that the pH value does not fall below 3.0. The basic ferric sulphate so precipitated is then in a filterable form. In a second tank, further acidic solution is added to leach out any excess zinc and so ensure that the iron precipitate carries a minimum of zinc with it to the residue. Further leaching time is allowed in another two tanks. The pH value is maintained at about 2.3 throughout the leaching step. The following chemical reaction gives an approximate description of the precipitation:

\[Fe_2(SO_4)_3 + 2Zn(OH)_2 = Fe_2O_3.SO_3.H_2O + 2ZnSO_4 + heat.\]

Fig. 10 compares the methods for the precipitation of iron and the extraction of zinc in these processes. A direct leach of the zinc sulphide concentrate at an elevated temperature and in the presence of oxygen
developed by Sherritt Gordon\textsuperscript{29,30}. This method is now applied on a plant scale, and elemental sulphur is produced as a byproduct. A direct leach of the concentrate eliminates the roasting step and the subsequent precipitation of iron that are required during the conventional roast–leach process.

**PRODUCTION OF ZINC IN SOUTH AFRICA**

In 1968 the Zinc Corporation of South Africa Limited (Zincor) started to produce zinc from an electrolytic smelter established near Springs. The main partners in Zincor are Gold Fields of South Africa Limited and the Iron & Steel Industrial Corporation (Pty) Limited (Iscor). This only smelter was initially fed with concentrates imported from Australia (Broken Hill South, Broken Hill North, Cobar, and Mathilda) and Canada (Pine Point), but it was later fed with sulphide concentrates from Prieska, Rosh Pinah (Namibia), and Perring, and with zinc oxide produced by Kiln Products (Namibia), as these concentrates became available.

Whereas zinc metal was previously imported from Zaire and Zambia, it is now produced in South Africa, and today the smelter at Springs is capable of providing the country's entire needs. The plant was initially designed for the annual production of 36 kt of zinc, but production has increased over the years to keep pace with the South African demand.

Fig. 11 gives an abbreviated flow diagram of the electrowinning plant at Zincor.

**Roasting**

Zincor uses four Lurgi turbulent-layer roasters to roast the zinc sulphide concentrates to zinc oxide. The off-gases are fed to two Monsanto interpass absorption acid plants built by Simon Carves. The total roasting capacity is 634 t of concentrate per day, and the two acid plants were designed for 540 t of acid per day.

Concentrates with a moisture content of approximately 8 per cent are fed into the burning beds of the roasters via slinger belts. The roasting temperatures are maintained at about 930 °C by the use of water addition. During roasting, the following chemical reactions take place:

\[
\begin{align*}
2\text{ZnS} + 3\text{O}_2 & = 2\text{ZnO} + \text{SO}_3 + \text{heat} \quad \text{(1)} \\
4\text{Fe}_2\text{S}_3 + 11\text{O}_2 & = 2\text{Fe}_3\text{O}_4 + 8\text{SO}_2 + \text{heat} \quad \text{(2)} \\
\text{ZnO} + 4\text{Fe}_2\text{O}_3 & = \text{ZnFe}_2\text{O}_4 \quad \text{(3)} \\
2\text{ZnO} + 2\text{SO}_2 + \text{O}_2 & = 2\text{ZnSO}_4 \quad \text{(4)}
\end{align*}
\]

Reactions (1) and (2) proceed to more than 99 per cent completion, whereas reaction (3) depends on the roasting temperature and on the association of the iron with the zinc. Iron that is part of the crystal, such as in marmatite, reacts completely with the zinc ferrite, whereas iron contained in separate minerals, such as in pyrite, will react only partially to form ferrite. Reaction (4) proceeds to approximately 6 per cent completion. The sulphur dioxide gas, after being cleaned and dried, is oxidized with air to sulphur trioxide and reacted with water to form sulphuric acid. This reaction takes place in ceramic packed towers, where the sulphur trioxide is brought into contact with concentrated sulphuric acid.

Fig. 12 is a diagram of a roasting plant similar to that at Zincor, and Table III gives details of the installed roaster and acid plants.

**Leaching**

The calcine is leached in three stages (Fig. 13). The first stage is conducted continuously by the addition of dry calcine to an air-agitated pachuca together with return acid from the electrolytic section. Slurry from the 300 m$^3$ pachuca overflows into a second and into a third pachuca, from where it flows to a thickener. The thickener underflow is filtered on stainless-steel drum filters. The second stage of leaching is conducted countercurrent to
TABLE III
CAPACITY OF ROASTER AND ACID PLANTS AT ZINCOR

<table>
<thead>
<tr>
<th>Year</th>
<th>Lurgi roasters*</th>
<th>Acid plants†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Capacity t/d</td>
</tr>
<tr>
<td>1968</td>
<td>2</td>
<td>117</td>
</tr>
<tr>
<td>1975</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>1980</td>
<td>1</td>
<td>200</td>
</tr>
</tbody>
</table>

* The feed to the roasters is given in dry tons of zinc concentrate per day
† The product of the acid plants is given in tons of 100 per cent sulphuric acid per day

the third stage. During the latter two stages of leaching, the temperature is kept at above 80 °C, and the acid concentration is maintained at above 10 and 40 g/l for the second and third stages respectively. Mechanically agitated tanks are used, and the residence time per stage is approximately six hours. The solution from the second leaching stage proceeds to iron precipitation.

Purification

The zinc sulphate solution obtained after leaching contains impurities that are detrimental to electrolysis. These are removed during the three stages of a continuous purification operation (Fig. 14).

Copper is precipitated in a 200 m³ 316L stainless-steel flat-bottomed agitator, the cyclone underflow from the cadmium-purification stage being used as the precipitant. The copper precipitate is filtered off on plate-and-frame presses, and the solution proceeds to the next stage of purification, where impurities such as cobalt, nickel, antimony, germanium, and arsenic are precipitated. The solution is then treated with zinc dust for the cementation of any residual cadmium. Finally, the filtered solution is pumped over cooling towers and stored in mild-steel rubber-lined tanks.

Electrowinning

Electrolysis is used on the purified solution to plate the zinc onto aluminium cathodes, the plated zinc being stripped off manually on a 24-hour cycle. Oxygen is liberated from the anodes, which are manufactured from lead containing 0.5 per cent silver and 0.05 per cent calcium. The current density at Zincor is 600 A per square metre of cathode area, and the cathode–anode potential is approximately 3.6 V. The power consumption is about 3400 kW per tonne of cathode zinc. This consumption can be reduced by the use of larger electrodes and operation at lower current densities, but it would then be necessary to introduce automatic stripping to handle the heavier cathode-zinc plates.

Zincor uses four transformer–rectifier units. The incoming feed of 42 kV is stepped down and rectified to direct current, which is fed to the electrolytic cells, each of which contains forty cathodes and forty-one anodes connected electrically in parallel. Twelve cells are connected in series to form a bank, and twelve to sixteen banks are further connected in series to form a circuit. Fig. 15 shows the electrical flow diagram for one circuit.

Each cell is fed individually with electrolyte, and the overflows from the individual cells are collected in a main return launder (Fig. 16). Some of the return or pent electrolyte is pumped to the leach, and an approximately equal volume of purified solution is added to the feed.

---

Fig. 13—Flow diagram of the leaching plant at Zincor
The reactions taking place during electrolysis are as follows:

\[
\begin{align*}
2\text{ZnSO}_4 + 4\text{H}_2\text{O} &= 2\text{Zn}^2+ + 2\text{SO}_4^{2-} + 4\text{H}_2\text{O} \\
2\text{H}_2\text{O} &= 2\text{H}^+ + 2\text{OH}^- \\
2\text{OH}^- &= \text{O}_2 + 2\text{H}^+ + 4\text{e} \\
2\text{Zn}^2+ + 4\text{H}_2\text{O} &= 2\text{Zn} + 2\text{H}_2\text{SO}_4 + \text{O}_2.
\end{align*}
\]
Melting and Casting

At Zincor, the stripped cathode zinc is prepared for marketing as follows: it is melted at 500 °C and cast into 25 kg slabs, which are strapped into 1 t pallets. Demag induction-heated furnaces are used for melting the zinc, a small amount of ammonium chloride being added as a flux.

Five grades of zinc can be produced for sale under Specification 20-1977 of the South African Bureau of Standards. These are shown in Table IV.

The zinc metal produced in South Africa during the past 22 years is illustrated in Fig. 17.

Uses of Zinc and Zinc Chemicals

Zinc is used mainly on iron and steel as a protective coating against corrosion, but it is also used in various alloys containing copper or aluminium. Other applications include the manufacture of dry-cell battery cans, zinc dust, zinc oxide, and a large number of zinc chemicals32,33.

### TABLE IV

**CHEMICAL COMPOSITION OF PRIMARY ZINC INGOTS**

<table>
<thead>
<tr>
<th>Metal designation</th>
<th>SA code no.</th>
<th>Zn</th>
<th>Pb</th>
<th>Cd</th>
<th>Fe</th>
<th>Sn</th>
<th>Cu</th>
<th>Al</th>
<th>Tl</th>
<th>In</th>
<th>Total Pb, Cd, Fe, Sn, Cu, Al, Tl, In</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td>Min</td>
<td>99,995</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>99,95 SHG*</td>
<td>Max</td>
<td>-</td>
<td>0,001 5</td>
<td>0,001 5</td>
<td>0,001 0</td>
<td>0,001 0</td>
<td>0,001 *</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0,001 0,005</td>
</tr>
<tr>
<td>Zn</td>
<td>Min</td>
<td>99,99</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zn 99,99 Zn 1</td>
<td>Max</td>
<td>-</td>
<td>0,003 0</td>
<td>0,003 0</td>
<td>0,002 0</td>
<td>0,001 0</td>
<td>0,002 0</td>
<td>0,005</td>
<td>0,001</td>
<td>-</td>
<td>0,005 0,01</td>
</tr>
<tr>
<td>Zn</td>
<td>Min</td>
<td>99,95</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zn 99,95 Zn 2†</td>
<td>Max</td>
<td>-</td>
<td>0,03</td>
<td>0,02</td>
<td>0,01</td>
<td>0,001</td>
<td>0,002</td>
<td>0,005</td>
<td>0,001</td>
<td>-</td>
<td>0,005 0,05</td>
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<tr>
<td>Zn 99,5 Zn 3</td>
<td>Min</td>
<td>99,5</td>
<td>0,35</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zn 99,5 Zn 4</td>
<td>Max</td>
<td>-</td>
<td>0,45</td>
<td>0,05</td>
<td>0,03</td>
<td>0,001</td>
<td>-</td>
<td>0,005</td>
<td>0,001</td>
<td>-</td>
<td>0,005 0,5</td>
</tr>
<tr>
<td>Zn 98,5 Zn 4</td>
<td>Max</td>
<td>-</td>
<td>0,95</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Selected high grade
* The maximum permissible aluminium content shall be a matter of agreement between manufacturer and purchaser
† In the case of Zn 2, the combined arsenic and antimony content shall not exceed 0,0005 per cent

**Fig. 17**—Zinc metal produced by Zincor during the period 1968 to 1990
The South African uses of zinc in 1990 are given in Table V. For comparison, the uses of zinc in Japan and the UK in 1989 are given in Table VI.

### Table V

**ZINC USED IN SOUTH AFRICA DURING 1990**

<table>
<thead>
<tr>
<th>Application</th>
<th>t</th>
<th>Usage %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galvanizing</td>
<td>65 376</td>
<td>75,6</td>
</tr>
<tr>
<td>Zinc alloys</td>
<td>9 599</td>
<td>11,1</td>
</tr>
<tr>
<td>Fabricated zinc</td>
<td>1 730</td>
<td>2,0</td>
</tr>
<tr>
<td>Zinc dust</td>
<td>1 037</td>
<td>1,2</td>
</tr>
<tr>
<td>Battery cans</td>
<td>6 745</td>
<td>7,8</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>1 989</td>
<td>2,3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>86 476</strong></td>
<td><strong>100,0</strong></td>
</tr>
</tbody>
</table>

### Table VI

**USES** OF ZINC IN JAPAN AND THE UK IN 1989

<table>
<thead>
<tr>
<th></th>
<th>Japan</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galvanizing</td>
<td>63,7</td>
<td>43,5</td>
</tr>
<tr>
<td>Zinc–copper alloys</td>
<td>13,5</td>
<td>21,3</td>
</tr>
<tr>
<td>Die casting</td>
<td>12,4</td>
<td>18,0</td>
</tr>
<tr>
<td>Zinc oxide</td>
<td>4,8*</td>
<td>9,0</td>
</tr>
<tr>
<td>Zinc dust</td>
<td>2,6</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>5,6</td>
<td>5,7</td>
</tr>
<tr>
<td><strong>Total, t</strong></td>
<td><strong>777,300</strong></td>
<td><strong>244,0</strong></td>
</tr>
</tbody>
</table>

* Includes other chemicals

### Metallic Coatings

Zinc metallic coatings are applied by hot-dip galvanizing, continuous-line galvanizing, electro-galvanizing, plating, spraying, and painting with zinc-bearing paints

A particular industry that can benefit from the extensive use of galvanizing is the automotive industry—not only for corrosion protection, but also for increased structural rigidity as was demonstrated by the hot-dip galvanizing of a production Renault car.

Recent developments in the galvanizing of steel sheet include the use of molten zinc-alloy baths. In the zinc-alloy galvanizing process, which has been in use for some years in the USA and Australia, the bath contains 55 per cent aluminium and 1,5 per cent silicon, with the balance as zinc. The newer Galvan process uses a bath of 5 per cent aluminium and small amounts of rare-earth metals. The advantages of these two processes over conventional galvanizing are that they provide higher corrosion resistance, higher ductility, and good protection of edges.

### Die-casting Alloys

Zinc as a structural material is contained in alloys for pressure die casting. The automotive industry is a large consumer, where the uses include mechanical components, handles, locks, light fittings, and other components. The second-largest market for zinc die castings is the building industry, where the applications include locks and keys, hand tools and cutlery, bathroom and plumbing fittings, and general hardware. The compositions of various die-casting alloys are given in Table VII.

Aluminium decreases the solubility of iron in zinc to the extent that a submerged-plunger type of die-casting machine can be used. Aluminium also improves the die-cast strength and reduces the grain size. However, an aluminium content of less than 3,5 per cent impairs surface finish and promotes hot shortness. A loss of impact strength begins at 4,5 per cent, and at 5 per cent the alloy is brittle. The presence of certain impurities (e.g. lead and tin) can result in intergranular corrosion in die castings exposed to moist, warm atmospheres. For this reason, special high-grade zinc is used in die-casting alloys.

Copper offers some protection against intergranular corrosion, and also increases the tensile strength and hardness.

Magnesium counteracts the harmful effects of small amounts of impurities such as tin and lead, and thereby prevents intergranular corrosion. It also increases the strength and hardness.

Cadmium adversely affects hot shortness and castability, and special high-grade zinc must be selected to meet this requirement in the preparation of the alloy.

Iron in small quantities has no detrimental effect on the permanence or other properties of these alloys, but an excess of iron may affect the machining and buffing of castings.

Die casting with zinc-based alloys is one of the most efficient production methods for the manufacture of accurate and complex metal components. The injection pressures for hot-chamber machines are between 6,9 and 20,7 MPa. During the 1970s, ILZRO (International Lead–Zinc Research Organization) developed casting techniques for the production of thin-wall zinc die castings. Because of the resulting mass savings per part, zinc became cost- and mass-competitive with aluminium and plastics. Castings of up to about 3 kg can be made with walls approximately 0,75 mm thick.

A pore-free process is still in the developmental stage for die-casting. In this process, the air in the cavities is displaced with oxygen or other reactive gas and, when the die is charged with molten alloy, the zinc reacts with

### Table VII

**CHEMICAL COMPOSITION OF ZINC DIE-CASTING ALLOYS**

<table>
<thead>
<tr>
<th>Metal designation</th>
<th>Code no.*</th>
<th>Alloying constituents, %</th>
<th>Impurities, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Al</td>
<td>Mg</td>
</tr>
<tr>
<td>ZnAl 4</td>
<td>ZA 1</td>
<td>3,9</td>
<td>4,3</td>
</tr>
<tr>
<td>ZnAl 4 Cu 1</td>
<td>ZA 2</td>
<td>3,9</td>
<td>4,3</td>
</tr>
</tbody>
</table>


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the gas to form solid particles that are dispersed throughout the pore-free casting.

High-strength Alloys

High-strength zinc foundry alloys have mechanical properties equal or superior to those of many brass, bronze, aluminium, and iron alloys. These alloys are manufactured to contain 8, 11, or 27 per cent aluminium. Their chemical composition is shown in Table VIII.

TABLE VIII
COMPOSITIONS OF HIGH-STRENGTH ZINC FOUNDRY ALLOYS

<table>
<thead>
<tr>
<th>Element</th>
<th>Composition, % by mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>8.0 to 8.8</td>
</tr>
<tr>
<td></td>
<td>10.5 to 11.5</td>
</tr>
<tr>
<td></td>
<td>25 to 28</td>
</tr>
<tr>
<td>Cu</td>
<td>0.8 to 1.3</td>
</tr>
<tr>
<td></td>
<td>0.5 to 1.25</td>
</tr>
<tr>
<td></td>
<td>2.0 to 2.5</td>
</tr>
<tr>
<td>Mg</td>
<td>0.015 to 0.03</td>
</tr>
<tr>
<td></td>
<td>0.015 to 0.03</td>
</tr>
<tr>
<td></td>
<td>0.01 to 0.02</td>
</tr>
<tr>
<td>Fe</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>0.075</td>
</tr>
<tr>
<td></td>
<td>0.10</td>
</tr>
<tr>
<td>Pb</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>0.004</td>
</tr>
<tr>
<td>Cd</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>0.003</td>
</tr>
<tr>
<td>Sn</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>0.002</td>
</tr>
<tr>
<td>Zn</td>
<td>Balance</td>
</tr>
<tr>
<td></td>
<td>Balance</td>
</tr>
<tr>
<td></td>
<td>Balance</td>
</tr>
</tbody>
</table>

High-strength alloys are used in industrial structural parts, office equipment, business machines, builders' hardware, and marine applications. Alloy No. 12 is used in bearings and bushings. The latter have been tested in mine elevators, drill motors, 501 dump trucks, and drill-track rollers. Zinc-based bearings and bushings may find acceptance as a substitute for bronze because of their lower cost and superior mechanical properties for low-speed high-load service.

Zinc alloys, unlike most other alloys, can be cast in many types of moulds including silicone rubber and graphite. Silicone rubber offers some special advantage because of its flexibility; for example, parts with reverse taper can be cast in these moulds.

Some of the properties of high-strength zinc foundry alloys are given in Table IX.

Rolled Zinc

Rolled zinc products in the form of strip, sheet, wire, and rod have many commercial applications. Strip is used for the manufacture of dry-cell battery cans, organ pipes, grommets, and other objects, some of which are subsequently plated with brass or chromium. A new application is the minting of US cent pieces from strip (consisting of zinc and 0.8 per cent copper). The blanks are barrel-plated with copper prior to coining for the production of the finished coin.

Special high-grade zinc with a maximum iron content of 0.0014 per cent in the form of plate and rods is used for the cathodic protection of steel in marine and pipeline applications.

Zinc Dust and Powder

Zinc dust is produced by the condensation of zinc vapour, and zinc powder is obtained by the atomization of molten zinc.

Zinc dust is used in paint and, when applied to iron or steel, it gives galvanic protection similar to that provided by a galvanized coating. Zinc-rich paint is used where conventional galvanizing is not suitable. The dust is also used in the sheradizing process, where the work pieces are tumbled in rotating steel drums in the presence of zinc dust at temperatures ranging from 370 to 420 °C. Zinc dust can be used as a reducing agent in processes such as the precipitation of gold from cyanide solution and the production of hydrosulphide compounds.

Zinc powder is used mainly to purify the solution in electrolytic-zinc plants. It is also used in primary batteries, spray metallizing, and chemical formulations.

Zinc Chemicals

The rubber industry is the largest user of zinc oxide, which is added as a vulcanization activator and accelerator, and to slow the aging of rubber by neutralizing the organic acids formed by oxidation. It also acts as a heat conductor and absorber of ultraviolet light.

Zinc oxide in paints serves as an acid buffer, as well as a pigment. It is used in animal feeds, fertilizers, and dental cements. Added to glasses, zinc oxide imparts low thermal expansion, low melting point, and increased chemical resistivity. The semi-conducting property of a variety of glasses and ceramics is based on their zinc oxide content.

Zinc chloride is used for wood preservation, fluxes, and batteries. It is also used as a mordant in dyeing and the parchmtenizing of paper. Other uses include the synthesis of organic chemicals such as methyl chloride and diethylzinc.

Zinc sulphate is used in the manufacture of the pigment lithopane (ZnS·BaSO4) and in fertilizers and animal feeds. Other uses include textile dyeing and printing, mineral flotation, electro-galvanizing, rayon manufacture, paper bleaching, and glue.

Other zinc chemicals are also used in industry, and Farnsworth and Kline list no fewer than forty-two with their various applications.

TABLE IX
SOME PROPERTIES OF HIGH-STRENGTH ZINC FOUNDRY ALLOYS

<table>
<thead>
<tr>
<th>Property</th>
<th>Alloy No. 8</th>
<th>Alloy No. 12</th>
<th>Alloy No. 27</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Permanent-mould cast</td>
<td>Sand cast</td>
<td>Permanent-mould cast</td>
</tr>
<tr>
<td>Density, g/cm³</td>
<td>6.37</td>
<td>6.03</td>
<td>6.03</td>
</tr>
<tr>
<td>Melting range, °C</td>
<td>375 to 404</td>
<td>377 to 432</td>
<td>377 to 432</td>
</tr>
<tr>
<td>Tensile strength, MPa</td>
<td>221 to 225</td>
<td>276 to 310</td>
<td>310 to 345</td>
</tr>
<tr>
<td>Yield strength, 0.2% MPa</td>
<td>207</td>
<td>207</td>
<td>214</td>
</tr>
<tr>
<td>Elongation, %</td>
<td>1 to 2</td>
<td>1 to 3</td>
<td>4 to 7</td>
</tr>
</tbody>
</table>
MARKETING AND FUTURE PROSPECTS

The production and consumption of zinc in South Africa and the world are compared in Table X.\textsuperscript{34}.

Zincor's sales of zinc for the period 1982 to 1990 are shown in Fig. 18.

![Graph showing Zincor's sales for the period 1982 to 1990]

**Fig. 18—Zincor's sales for the period 1982 to 1990**

The market for zinc shows opportunities for growth through the simple expansion of its uses\textsuperscript{5} and through the application of new materials (for example, a greater use of zinc coatings for steel, and new uses for zinc–aluminium foundry alloys, respectively). A third growth opportunity is the development of completely new markets (for example, the recent introduction of zinc as a coinage metal in the USA). The largest competitor for zinc is plastics, which are being used as protective coatings. There has even been talk of producing non-rubber tyres consisting of polyurethanes and thereby eliminating the use of zinc oxide in tyres.

ILZRO has estimated that the total effort in basic research, product research, and market development expended by producer and user companies totals 0.25 to 0.30 per cent of the metal sales\textsuperscript{7}. An estimate of the expenditure on market development for competitive materials equals 1.5 to 2.0 per cent of turnover. For aluminium, this level of expenditure is approximately 2.0 per cent, and the paint industry spends between 0.5 and 1.0 per cent. From these figures, it would appear that the future uses of zinc will be related to the effort being put into research and market development.

ACKNOWLEDGEMENT

This paper is published with the permission of Gold Fields of South Africa Limited.

REFERENCES


**TABLE X**

COMPARISON OF WORLD AND SOUTH AFRICAN STATISTICS FOR THE PRODUCTION AND CONSUMPTION OF ZINC

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine production SA*</td>
<td>96.9</td>
<td>101.9</td>
<td>112</td>
<td>89.6</td>
<td>77.3</td>
<td></td>
</tr>
<tr>
<td>World</td>
<td>7038.6</td>
<td>6999.1</td>
<td>7315.2</td>
<td>7088.1</td>
<td>7148.9</td>
<td></td>
</tr>
<tr>
<td>Slab production</td>
<td>93.7</td>
<td>80.8</td>
<td>96.1</td>
<td>84.4</td>
<td>85.0</td>
<td>92.3</td>
</tr>
<tr>
<td>World</td>
<td>6859.8</td>
<td>6798.6</td>
<td>7051.6</td>
<td>7239.9</td>
<td>7224.3</td>
<td></td>
</tr>
<tr>
<td>Consumption</td>
<td>84.4</td>
<td>83.1</td>
<td>92.4</td>
<td>87.5</td>
<td>87.0</td>
<td></td>
</tr>
<tr>
<td>World</td>
<td>6507.7</td>
<td>6696.8</td>
<td>6910.2</td>
<td>7185.9</td>
<td>7158.6</td>
<td></td>
</tr>
</tbody>
</table>

* Excludes Namibia
† Includes Namibia

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