

## Engineering Exposure related to Aluminium Production



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## Introduction

Aluminium is a relatively young material. It was discovered (and named) in 1808 and has been commercially produced for only 150 years. And yet today its production volume exceeds that of all other non-ferrous metals combined. More than 29 million tonnes of primary aluminium was produced in 2004 and its importance for the world economy and industry can hardly be overestimated. Due to a number of valuable properties such as light weight, strength and rigidity, high corrosion resistance, excellent conductivity of electricity and heat, aluminium and its alloys have found a variety of applications in the transport, construction, packaging and electrical industries.

Aluminium is the most abundant metal in the Earth's crust and the third most abundant of all elements after oxygen and silicon. However, it does not occur in the elementary form in nature and only exists in very stable combinations with other materials (particularly as silicates and oxides). The group of minerals, which contain the hydrated form of aluminium oxide and called bauxites is the base raw material for aluminium production. In some areas (for example, in eastern Siberia) a less rich ore – nepheline is also used.

Production of aluminium finished products is a multistage process where separate operations are usually undertaken at different sites.

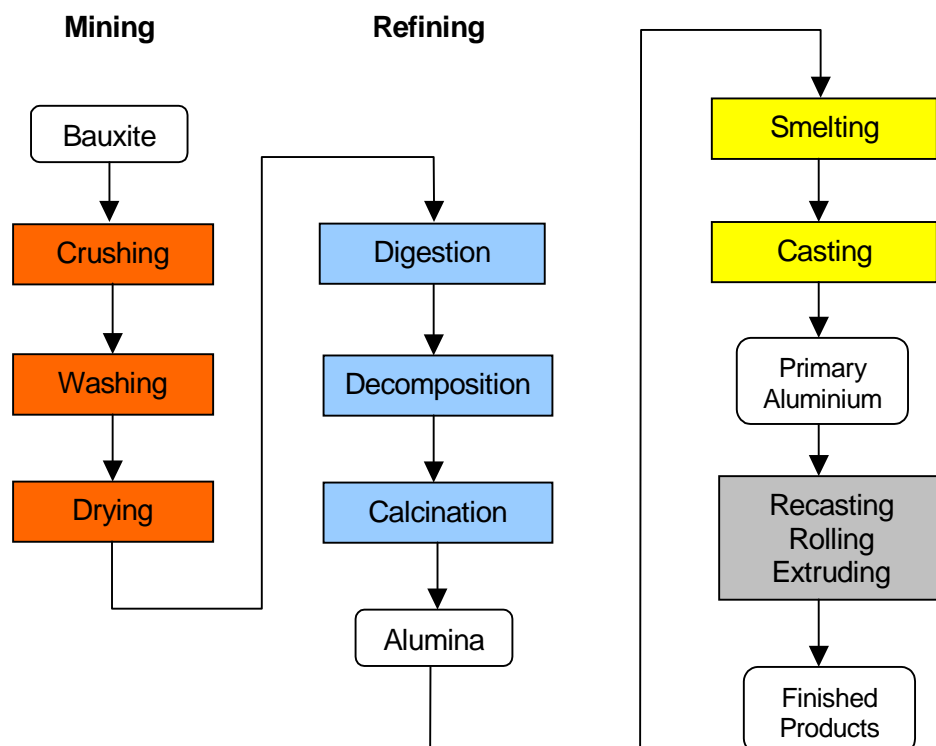


Figure 1. Simplified process flow from bauxite to aluminium finished products

The aluminium ore, bauxite, is normally obtained by opencast mining. Today the most bauxite mining locations are in the Caribbean area, South America, Australia and Africa. Before the ore leaves the mining area it is usually crushed in ball mills and calcined (dried and heated) to remove organic substances and water. These operations reduce the ore's shipping weight and make handling easier. Approximately 150 million tonnes of bauxites are mined per year.

The second step in the production of aluminium is the recovery of alumina (aluminium oxide) from the bauxites by using a chemical refining process called the Bayer process. The process, which was invented in 1889 by German scientist, Karl Bayer, has several stages: digestion, clarification, precipitation and calcination. In few alumina refineries, where the feed stock is bauxite of not high purity the sinter process is also utilized. In this process the bauxite is crushed, dry milled and sintered with calcined soda and lime before digestion. The sinter process usually includes a desiliconisation step which improves overall product quality.

Two to three tonnes of bauxites are needed to produce one tonne of alumina. Annual production of alumina has steadily increased in recent years and reached 62 million tonnes in 2004 with largest amounts produced in Australia and New Zealand (27%), Latin America (19%), China (11%) and North America (11%).

The third stage involves reduction of alumina to molten metal, and takes place in alumina smelters which utilize modifications of the Hall-Héroult process. This process was invented in 1886 by Paul Louis Toussaint Héroult from France and Charles Martin Hall from USA who worked separately and unaware of each other's work. They discovered that if they dissolved aluminium oxide (alumina) in a bath of molten cryolite and passed a powerful electric current through it, then molten aluminium would be deposited at the bottom of the bath. The Hall-Héroult process is the basis for all aluminium production today.

Roughly two tonnes of alumina are needed to produce one tonne of molten metal in an electrolytic process that consumes very large quantities of power. Primary aluminium production facilities are located all over the world, often in areas where there are abundant supplies of inexpensive energy, such as hydro-electric power.

Considerable efforts have been made to improve the efficiency of the Hall-Heroult process. Before the Second World War the consumption of electricity in aluminium smelting averaged 23.3 kilowatt hours per kilo of metal produced, in 1950s it was reduced to 20 kilowatt hours, whereas today the most efficient plants run at close to 13 kilowatt hours per kilo.

Molten metal from the electrolysis cells ("pots") is cast into a variety of forms, ranging from small ingots or bars (typically weighing 10 to 20 kilos) to single slabs that may weigh 20 to 30 tonnes.

The fourth step, undertaken at metallurgical plants involves converting the primary metal slabs and billets into its final form. A common first step involves remelting the primary aluminium, alloying it with small quantities of other metals (such as magnesium, copper, and numerous others) and recasting the metal into new billets or slabs. Sometimes this process is completed at the smelter stage.

The two most common metallurgical processes are extrusion and rolling. In the extruding process a cylindrical aluminum billet is heated and extruded into a continuous length of uniform cross-section by forcing the billet through a steel die under high pressure. This process can produce bars, tubes, L-brackets, U-shaped rods and many products with unusually shaped cross-sections, including tapered cross-sections. Rolling turns cast aluminum into plate, sheet or foil. Rolling mills are either primary or finishing. Usually, primary mills are hot mills and finishing mills are cold mills. They are categorized by the product produced, such as plate, sheet or foil.

Finishing processes include cutting and stamping rolled strip into specific forgings, and extruding profiles into final composite products, such as window frames. Other common finishing processes include painting, laminating (with paper or plastic), printing, and injection moulding with polyurethane foam. However, none of these final finishing operations present exposures that are unique to the aluminium industry.

This paper will focus on alumina refining and primary aluminium production stages describing main processes and equipment and highlighting some industry specific risks. It does not, however, cover all possible perils at refineries and smelting plants, neither does it include those exposures, which are common for many other types of industry.

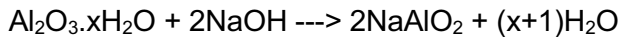
## 1. Alumina Production

### 1.1. Process and equipment

The most common and economical way to produce alumina ( $\text{Al}_2\text{O}_3$ ) is the Bayer process, although other processes are also used. The Bayer process is most suitable for bauxite with relatively low content of silica and sulphur. The process of producing pure alumina from bauxite has changed very little since the first plant was opened in 1893. The Bayer process can be considered in three stages:

#### ***Extraction***

The hydrated alumina is selectively removed from other (insoluble) oxides by transferring it into a solution of sodium hydroxide (caustic soda):



Bauxite is crushed in several crushing stages, with appropriate recycle routes for oversized materials, to achieve a very fine particle size. The crushed bauxite is mixed with strong caustic soda solution (sodium hydroxide) in large steam heated steel pressure vessels (autoclaves), which are called “digesters”. Digesters are arranged in banks, side by side and several dozen vessels can be involved in a single digestion plant. For some types of bauxites a little portion of calcined lime (2.5-5%) is added to the solution.

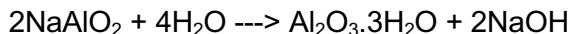
Conditions within the digester (concentration, temperature and pressure) vary according to the properties of the bauxite ore being used. Although higher temperatures are theoretically favoured these produce several disadvantages including corrosion problems and the possibility of other oxides (other than alumina) dissolving into the caustic liquor. Modern plants typically operate at between 200 and 240 °C and can involve pressures of around 30 atm. This stage typically lasts from 2 to 8 hrs.

The resulting liquor contains a solution of sodium aluminate and undissolved bauxite residues containing iron, silicon, and titanium known colloquially as “red mud”.

#### ***Decomposition***

Upon completion of the digestion stage, the salt bearing liquor and the residue (red mud) are sent to washing and settling tanks where the two components are separated. The settling tanks are very large vessels that operate at atmospheric pressure, and are slowly stirred by internal agitators. The sodium aluminate liquor is filtered and sent to “seeding tanks” (or “decomposition tanks”), and the red mud, after final washing or filtering, is sent to landfill lagoons.

Alumina in powder form is added to the sodium aluminate solution in the seeding tanks, causing aluminium hydroxide to precipitate out of the mother liquor as it cools:



This is basically the reverse of the extraction process, except that the product's nature can be carefully controlled by plant conditions (including seeding or selective nucleation, precipitation temperature and cooling rate). This process takes up to 60 hrs.

The wet precipitate is filtered out, washed, classified into size fractions and then sent to the final process stage, the calciners. The wash solution is returned to the decomposition tanks.

### **Calcination**

Alumina trihydrate crystals are calcined to remove water molecules. The calciners are high temperature (1100-1300°C) furnaces, frequently cylindrical rotating kilns. In these kilns, water is driven out of the aluminium hydroxide to produce the final product, alumina ( $\text{Al}_2\text{O}_3$ ), a white, inert powder. Alumina from the calciners is cooled, and then sent to storage silos to await shipment to the aluminium smelters.

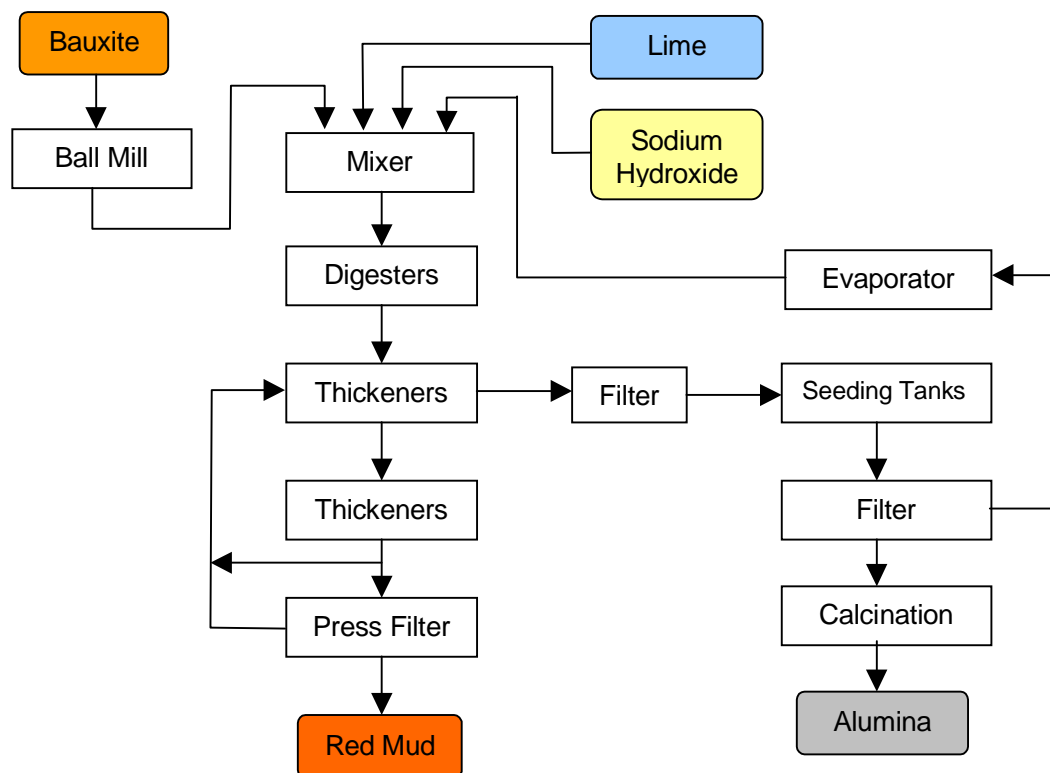


Figure 2. The Bayer process flow chart

## 1.2. Exposures related to alumina refining

There are few inherent risks associated with the alumina production process. The chemical processing of bauxite involves mainly large pressure vessels, settling tanks, crystallizers and boilers for steam production. The risks consequently tend to be related to machine failure since high pressure and temperature and chemicals are involved.

The most significant industry specific risk is that of mechanical overpressure of a digester vessel. In these vessels prepared aluminium ore (usually bauxite) reacts with caustic soda under very high pressure and temperature. The reaction is not exothermic, and there is no exposure to runaway chemical reaction. However, major explosions have occurred in the past due to failures of instrumentation and control devices and pressure relief systems. These accidents tend to be extremely violent, resulting in total destruction of the involved digester and significant damage to the building and other surrounding digesters, sometimes throwing debris many hundreds of metres away. Losses exceeding US\$100 million are on record. Special attention has to be paid on reliability of the control system for digesters, an arrangement must be made for alarm and subsequently shut down when excessive pressures or temperatures are detected.

Part of the treatment process involves use of vessels with slow moving agitators. Failure of a motor can cause the rotating blades to stop, and solids separating from the slurry can settle on top of them making restart difficult. Use of multiple stirred vessels would minimize this exposure.

Rotary kilns used for alumina calcining are exposed to severe damage due to deformation if a failure of electric power or breakdown of motor prevents them turning when at red heat. It is normal therefore to have the turning gear connected to the emergency busbar, fed from a totally independent source, usually a diesel driven generator, so that the kilns can still be turned independently of the main power. Supplementary donkey motors are usually installed to prevent heat damage due to failure of the primary drive. It is recommended to run these motors weekly to check their operational capability.



*Figure 3*  
*Rotary kilns at alumina refinery*



The fire hazards at alumina refineries are associated with oil leakage from the hydraulic and lubrication oil systems and with conveyor systems. As a result of dust deposits in the conveyor drives, heat due to friction can cause the belt to ignite. Accidents of this type lead to long production stoppages.

Other typical exposures at refineries include mechanical breakdown of heavy duty machinery such as rock crushers and mills, electrical breakdown of large motors, breakdown of conveyor systems, electrical failures in large transformers and switches, burst boilers and gas explosions in the steam production area.



*Figure 4.  
Motors for crushers*

## 2. Production of primary aluminium

### 2.1. Process and equipment

The basis for all modern aluminium smelting plants is the Hall-Heroult process. In this electrolytic process alumina (aluminium oxide,  $\text{Al}_2\text{O}_3$ ) is dissolved in a bath of molten cryolite (sodium aluminium fluoride,  $\text{Na}_3\text{AlF}_6$ ) through which extremely high DC current is passed at very low voltage.

The container in which the electrolytic process takes place in smelting plants is a large rectangular still tank (known as a “pot” or “cell”) lined with carbon blocks. The joints between blocks are filled with a carbon paste similar to that used for anode production. Thermal insulation consisting of refractory brick, vermiculite or similar material is placed between the steel shell and the carbon lining. This lining with embedded steel bars forms the cathode and the carbon anode is placed above the bath, mounted in electrically insulated superstructure.

Electric current of typically 150,000 amperes (in some modern plants up to 320,000 amperes) and 4-5 volts passing between the electrodes heats up the cryolite and it melts at about  $960^\circ\text{C}$ . The alumina dissolves in the molten electrolyte and forced by electric current the aluminium dioxide dissociates into aluminium metal and oxygen which reacts with carbon anode to produce carbon dioxide.



The smelting point of alumina is very high ( $2000^\circ\text{C}$ ) and using cryolite as a solvent for alumina allows to reduce considerably the temperature of the process. Some other substances such as aluminium fluoride and calcium fluoride are normally added to the electrolyte to reduce its melting point and thus to improve performance of the pots.

The smelting process is continuous and as it progresses the alumina content of the bath is decreased. Molten aluminium runs by gravity to the bottom of the cell where it slowly collects and from time to time the metal is siphoned out (or “tapped”) from the cell and transferred to the casting shop in crucibles.



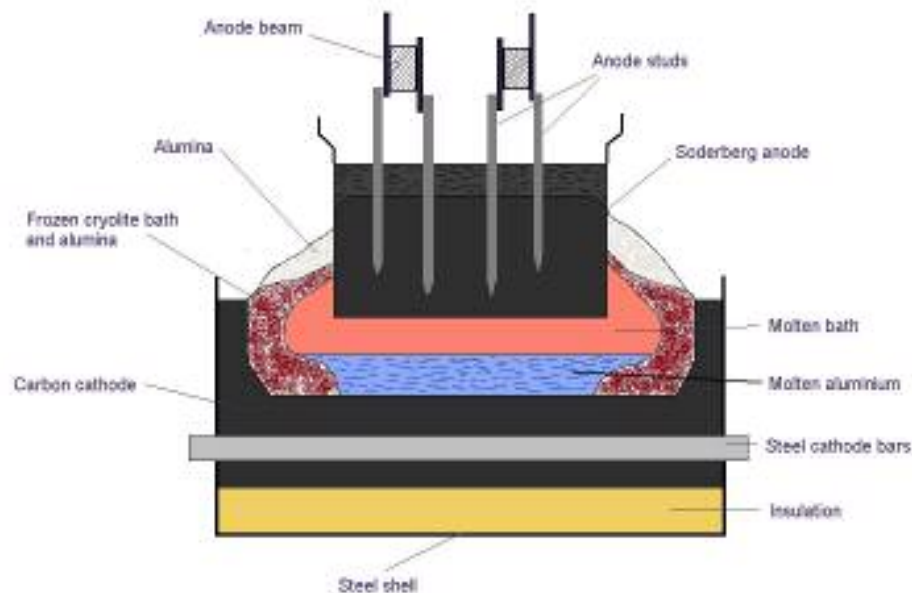
*Figure 5.  
A crucible waiting for  
use*

New portions of alumina (and additives) are periodically fed to the pot to maintain the dissolved aluminium dioxide content at about 2 to 5 percent. If the alumina concentration in electrolyte falls below 2%, the phenomenon of “anode effect” may occur when a gas film forms between the anode and bath resulting in a high electrical resistance. During anode effect, the pot voltage increases 5 to 10 times from normal level of 4 to 5 volts, leading to excessive energy consumption and drop of the pot output.

The effluent gasses which contain combustible substances are partially burned in the pot and then aspirated to the flue-gas purification plant where the acid components are neutralized by sodium hydroxide solution and the fluorine and solid residues are removed.

The carbon lining of cells has a limited lifetime and must be replaced in intervals of 4-6 years. Pots themselves typically last 3 cycles before they are in need of replacement

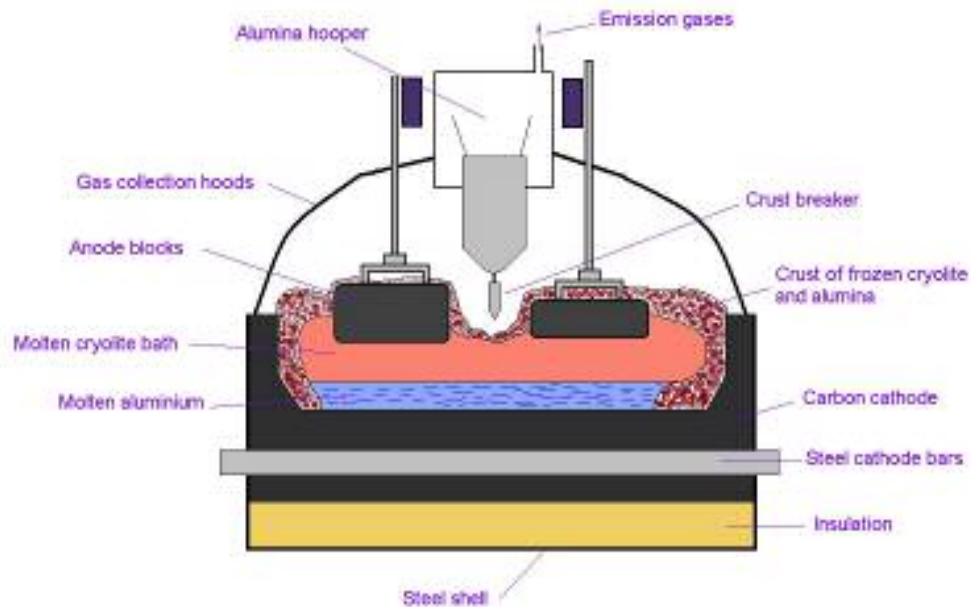
The anodes are slowly consumed in electrolytic process and hence new anodes have to be inserted in cells. Two technologies exist which use different type of anodes. In Söderberg process the anode takes the form of a metal skirt about a metre high, into which anode rods are inserted from above. The skirt is then filled with anode paste (dry briquettes) using specially designed vehicles. The open bottom of the skirt allows the briquettes to lie on top of the alumina charge, completing the circuit. As the process continues, the lower levels of briquettes are first baked into a solid mass, then they are consumed (see above), resulting in a need to regularly replenish the anode, by piling more briquettes onto the top of the anode skirt.



*Figure 6. Cross sections of a pot with Söderberg anode*

In modern smelters, the Söderberg arrangement of a skirt holding a reservoir of paste briquettes is replaced by use of pre-baked anodes which are made in a separate facility and attached to rods that suspend the anodes in the cell. The production processes for

both anode paste and pre-baked anodes are described in the next section. The advantage of using pre-baked anodes is improved environmental arrangements.



*Figure 7. Cross sections of a pot with pre-baked anode*

The newest primary aluminium production facilities use a variant on pre-bake technology called Centre Worked Pre-bake Technology (CWPB). This technology uses multiple "point feeders" and other computerized controls for precise alumina feeding. A key feature of CWPB plants is the enclosed nature of the process. Fugitive emissions from these cells are very low, less than 2% of the generated emissions. The balance of the emissions is collected inside the cell itself and carried away to very efficient scrubbing systems which remove particulates and gases.



*Figure 8.  
A pot with temporary  
removed hoods*

Computer technology controls the process down to the finest detail, which means that occurrence of the anode effect - the condition which causes small quantities of Perfluorocarbons (PFCs) to be produced - can be minimised. All new plants and most plant expansions are based on pre-bake technology.

The use of Söderberg anodes is in steady decline because of poorer energy utilization. The share of these electrodes worldwide is just about 15%, with a downward trend.

Cells in aluminium plants are arranged side-to-side in one or several lines (called “potlines”) in very long single storey buildings. Such arrangement allows carrying out almost all operations and maintenance by using overhead multipurpose cranes. In most designs the pots are situated above ground with solid metal bus bars located at ground level directly below them. Current flows from one cell to another dropping a fraction of a volt in each cell.



*Figure 9.  
A pot line of cells with  
pre-baked anodes*

The smelting process requires large amounts of electricity. Alternating current (AC) produced on site or supplied from the grid must be transformed into direct current (DC). This requires the use of large rectifiers, transformers and sophisticated monitoring systems. These are usually outside the pot line building, but sited close to it.

Most modern plants have the production capacity of 150,000 to 300,000 tonnes per year and consist of one to six potlines, each potline consisting of 100 to 300 individual cells, whereas the largest individual smelting plant has the capacity of about 1 million tonnes and accommodate more than 2300 pots arranged in 25 potlines.

## **2.2. Exposures related to smelting plants**

Obviously, the major inherent risk in aluminium production is a loss of electrical power leading to freezing of pots. A failure of electricity supply or distribution system lasting just a few hours can cause the electrolyte in the pots to cool to the point where its electrical resistance is too great to restart the line when power is restored. For various pot lines the freezing up time in case of power supply interruption is in the range from 3-4 h to 6-7 h.



It is expensive and time consuming to restart a frozen pot line. Apart from the obvious loss of production a pot line freezing can damage the pot linings because the solidified aluminium and electrolyte must be physically broken out of the pot. For pots that have been recently relined, the damage may be slight and restart can proceed without repair work, however the remaining pot life will be reduced. For pots that are already well into their predicted lifetime, a freeze up is likely to result in bringing the scheduled reline forward. Besides, even if a restart is possible, the pot efficiency will be reduced until its return to normal operational conditions which means a certain loss of production.

Complete restoration of a pot line can take up to several months. This is primarily because pot lines are usually staffed and equipped to reline only a limited number of pots per month, on a scheduled basis. The work involved in simultaneously relining many pots is usually beyond the installed facilities at most smelters. Hence, apart from the costs of pots relining, which is typically between US\$ 50,000 and US\$ 100,000 per pot, significant business interruption losses will be incurred in the case of a pot line freezing.

A reliable and uninterrupted electric power supply is therefore a critical issue for aluminium smelters. Electricity can be produced on site, by the smelter's own generating plant or bought from the public grid. According to the IAI statistics 27% of electric power used in primary aluminium production in 2003 was self-generated, the rest was purchased. About 50% of electricity consumed was sourced from hydroelectric power plants, 36% - from coal fired plants, 9% - from gas fired stations and 5% from nuclear power plants.

General aspects of reliability of the grid are beyond the scope of this paper as well as various failures of power generating machinery (which are the topics of a number of other IMIA papers), however some comments should be made here on the power supply layout.

An adequate degree of redundancy must be built in the electric power supply system to ensure good supply continuity. A secure power supply system shall include the following features:

- the dual supplies from the grid or from the grid and on-site power plant;
- surplus capacity of installed generating facilities at regional grid or local suppliers;
- the smelter's connection to the grid arranged by two or more independent transmission lines so that in case of failure of any one the rest would provide 100% of the required power;
- duplication of line transformers and other major equipment in the switchgear yard;
- dual circuit connections to pot lines within the plant;
- separation of transformers and rectifiers with space and/or fire walls, providing emergency oil drainage and standard safety devices including gas detection;
- installation of at least one spare power transformer and one spare rectifier for each pot line. If transformers in the plant vary and are not interchangeable, more spares are needed;
- extensive transmission routes allowing considerable flexibility of supply.

Loss of power does not cause pots to freeze instantly. If a smelter operator is aware that pot line freeze up is inevitable, there are several steps that can be taken in an emergency to prepare the pots for freezing in such a way that later restart can be made as simple as possible. The most important emergency step is to siphon off as much molten metal as possible before freezing occurs, but obviously to do this, adequate specialized pot tending vehicles must be available. Secondly, the anodes should be lowered as far into the pot as possible to assist restarting when molten metal is

eventually poured in when the pot is restored to service. This may be difficult in the event of absolute and total power failure.

However, even if a large proportion of electricity is lost, freezing a pot line may not be inevitable. Although considerable power is needed to allow the electrolysis process to proceed, far less power is needed to keep the pots molten, but producing nothing. A relatively short burst of power on a periodic basis can achieve this, and by positive crisis management, each pot in a line can be held in temporary hibernation until power becomes available again. Clearly, this emergency mode is economically unsustainable for an indefinite period, but for a few days, it may be preferable to letting the lines freeze.

The above illustrates how important emergency planning is for loss mitigation in the case of a power failure. The plant management must develop a procedure of preparations for an unavoidable pot freeze according to the type of pots in use, establish criteria to determine when the pots will be emptied and train employees when and how to empty them. A pot line recovery program must be developed to permit starting as many as possible pots per day.

Other risks at smelting plants are repair and maintenance works on the electrolytic cells, which can cause a short circuit resulting in a failure of an entire line. Cable fires in the underground cable ducts and short circuits in the transformers and rectifiers likewise represent a serious hazard. Atmospheric discharges can also lead to short circuits, unless suitable protection is provided. This again leads to a risk of solidification of the electrolytic cell content.

### 3. Anode production

#### 3.1. Process and equipment

On average about 500 kg of anodes are spent to produce one tonne of aluminium. Anodes are made at the anode paste or pre-baked anodes plants (depending on the type of anodes used) of petroleum coke and pitch.

Coke from stores is sent to driers, then to kilns where it is heated to incandescence, in the absence of oxygen. This process produces a very pure form of carbon, with high strength and good electrical properties. Once the coke has cooled it passes to coke mills.

Pitch tanks have to be heated (usually by steam) irrespective of ambient temperature.

Coke dust and heated pitch (and 15-30% of recycled spent anodes at pre-baked anodes plants) are then mixed together under pressure and heated to 160°C in purpose designed kneading machines.

Anode paste (which visually resembles dry coke briquettes) is extruded from the mixers, and at smelters that use Söderberg cells, the paste is sent to storage prior to being moved to the pot lines. In anode plants that produce pre-baked anodes, the paste (which is still moist at this stage) is moved to vibro-compactors. In the vibro-compactors, the paste is formed under pressure into blocks whose dimensions are determined by the geometry of the pots into which they will later be inserted. A typical anode block may be up to 2 metres long, 1.2 metres wide and 1 metre high. Six to ten vertical holes, about 50 cm deep and 20 cm wide are formed in the top of the blocks during the vibrating process.

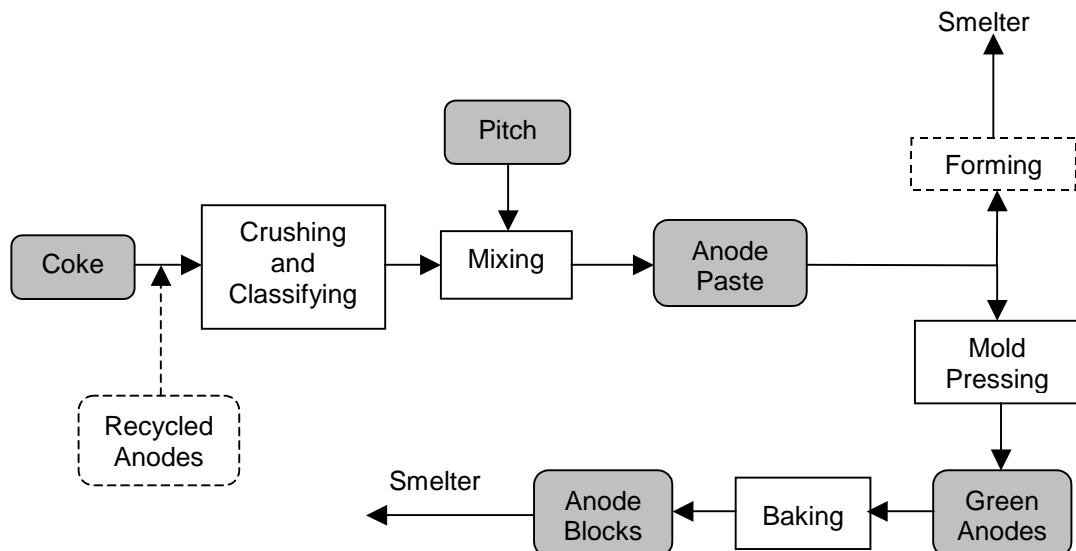


Figure 10. Anode production flow chart

The compacted blocks (known as “green anodes”) are relatively brittle at this stage, and must be baked before the next process. The baking operation takes place in a ring



furnace, which in simple terms is a series of several hundred refractory brick lined pits that occupy the floor of a large building. The pits are connected by air channels, and are heated by oil or gas fired burners. Green anodes are placed into cold pits with a blanket of coke covering the anodes and filling the space between the anode blocks and the walls of the pits. The pits are heated up to  $1,150^{\circ}\text{C}$  with natural gas, held at a high temperature over a period of several days, and then cooled down, the blocks having been baked. At any one time some of the pits are empty and cold, being prepared for the next batch of green anodes, some pits are heating up, some (the majority) are at a stable high temperature as the blocks bake, and some are cooling down. The cycle of placing green anodes into the ring furnace, preheating, firing, cooling and removal is approximately 18-20 days.

Baked blocks are removed from the ring furnace and sent to temporary storage. The baking process increases their strength significantly, and drives off most of the volatiles.

The final process is inserting anode rods into the holes in the top of the blocks. This is done in a rodding area, where the raw materials are new baked anode blocks and old used anodes returning from the smelter. The remains of the old blocks are removed from the rods (which are reusable), then cast iron is removed in a mechanical press, then the bottoms of the rods are ground clean.

Recycled rods are held in place with their ends inside the depressions in the new blocks, molten cast iron is poured into the depression, immediately solidifying and holding the rods in place. Finished blocks, with rods in place are then sent directly to the pot lines.



*Figure 11  
Anode blocks ready for  
use*

Not all aluminium smelting plants produce their own anodes. The anodes for a company with several smelters are often produced on and distributed from a single site. Since the anodes for the different technologies have different shapes, there are restrictions on the choice of manufacturers (problem with regard to production stoppage). On the other hand, anode paste itself in briquette form (for the smelter using Söderberg cells) is widely available.

### **3.2. Exposures related to anode production**

Anode production involves storage and processing of large quantities of pitch and coke, both of which are combustible; hence, the fire potential at anode plants is generally high. Production of anode paste is inherently a dirty operation; therefore, regular and frequent cleaning is essential to reduce build up of combustible dusts. The exhaust air system also should be cleaned regularly and protected by a sprinkler system, since deposits of pitch are formed here, and once ignited, they are practically impossible to extinguish due to difficult access. The paste manufacturing process requires heat, and in many paste plants a hot oil heat exchange system is used, which again presents a fire hazard. In addition, the heating of pitch (e.g. during the baking of the anodes) leads to the liberation of volatile combustible gases and vapours, which may be deposited in the exhaust air systems and so significantly encourage the spread of fire or lead to explosions.

Grinding the coke can also introduce a dust explosion risk, unless equipment is very well maintained, and housekeeping (dust removal) is excellent.

Rubber conveyor belts are often used to move materials around anode making plants, especially at the start of the process. All the usual risks associated with conveyor belts are normally present.

## 4. Casting

### 4.1. Process and equipment

Molten metal siphoned from the pots is moved in crucibles to casting shops where it is placed into electrically powered or gas/fuel oil fired holding furnaces, and then converted to finished products, which may be in a variety of forms. Common forms are small ingots (often referred to as “notch bars”), slabs and billets, both of which are much larger, weighing up to 20 or even 30 tonnes. Slabs are typically oblong blocks of metal up to a metre high, four metres wide and up to 12 metres long. “T” bars are similar but have shaped profiles with protrusions (the “T”s), to assist mechanical handling. Billets are usually smaller than slabs, and may be rectangular or cylindrical in cross section.

Small ingots and notch bars are produced by chain casters where molten aluminium is poured into metal moulds that travel on a conveyor belt below the pouring spout.



*Figure 12.  
A chain casting machine*

Direct chill casting is the most common method of producing large pieces. In the direct chill (“DC”) casters molten aluminium is poured into a “shoe”, which is a metal collar whose internal shape is that of the final cross section of the item being produced. The top of the shoe, into which aluminium is poured, is open. At the start of the pour, the bottom of the shoe is closed by a platen, which is a horizontal metal plate having the same shape as the cross section of the shoe.

The platen is supported from below using either chains (the “old” method), or in more modern casters, by a vertical hydraulic ram. Apart from other issues, use of a hydraulic ram allows smoother movement of the platen, and thus improves product quality.

Below the platen is a vertical pit that is as deep as the final length of the product required (typically between 8 and 12 metres). To start the cast, water is sprayed into the pit causing metal to freeze at the bottom of the shoe. Simultaneously the platen is slowly lowered, causing a solid piece of metal to emerge downwards from the base of the shoe. As solid metal is withdrawn from the bottom, additional molten metal is poured onto the top of the shoe, keeping it full. As the platen descends into the pit, the length of solid block increases, and by the end of the cast (when the platen reaches its lowest position), the solid block has been produced. Throughout this whole process,

water is sprayed at high rate onto the sides of the block as it drops lower into the pit. The bottom of the pit is usually full with water to a depth of several metres.

Continuous casting is now becoming common. A continuous caster is a combination casting machine and rolling mill. Molten aluminium is fed to the machine and emerges as re-draw rod for a rod mill or re-roll stock for a sheet mill.



*Figure 13.  
Aluminium ingots ready  
for transportation*

#### **4.4. Exposures related to casting plants**

The main hazard associated with casting plants is a molten aluminium spill. A spillage of molten aluminium into the base of the pit of DC casters will lead to a molten metal-water contact resulting in a violent explosion. Possible causes for aluminium spillage are overfilling of the shoe, and sudden or unexpected descent of the platen (this could allow molten aluminium to spill out of the bottom of the shoe). Platens can descend too fast for a number of reasons, human error being the prime cause in manually operated (older) equipment. Mechanical breakage of the support system or control failure on automated casters are other reasons. A typical DC caster may have a replacement cost in the region of US\$1 to 2 million, and a molten metal-steam explosion can damage a caster beyond repair.

Casting machines for small ingots come in two forms, air-cooled and water cooled. In water cooled a spill of molten aluminium and its contact with water again can cause an explosion resulting in considerable local damage.

Molten aluminium can also explode when it contacts rust on steel surfaces. It is necessary to protect all structural members exposed to molten aluminum spills with appropriate heat-resistant coating to a height of at least 1.8 m above the floor

Other risks at casting shops include combustion chamber explosions if fuel fired furnaces are used, and fire caused by ignition of hydraulic oils used in casting machines and hydraulic systems used to open and close heavy machinery.

Remelt shops also offer one further significant risk, that of steam explosions caused by accidental loading of furnace charge that contains water or ice. Such an event in England in the nineteen eighties destroyed a remelt furnace.

## References and Internet links:

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Brief description and key areas of risk  
Swiss Re Risk Management Services, 2000

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<http://www.world-aluminium.org>

Homepage of the International Aluminium Institute  
Site contains valuable information about history, development of technology, production and applications of aluminium and also various statistical data on production of alumina and primary aluminium.

[www.alcoa.com](http://www.alcoa.com)

Homepage of Alcoa Inc.  
Contains a technical article on aluminium smelting and video of aluminium production process.

[www.comalco.com](http://www.comalco.com)

Homepage of Comalco Aluminium Limited  
Contains "How Aluminium is Made" education module

<http://www.lme.co.uk>

London Metal Exchange  
Current and historical prices, stocks and traded volumes of aluminium.