

## IRON AND STEEL

Extracting iron from iron ore using a Blast Furnace

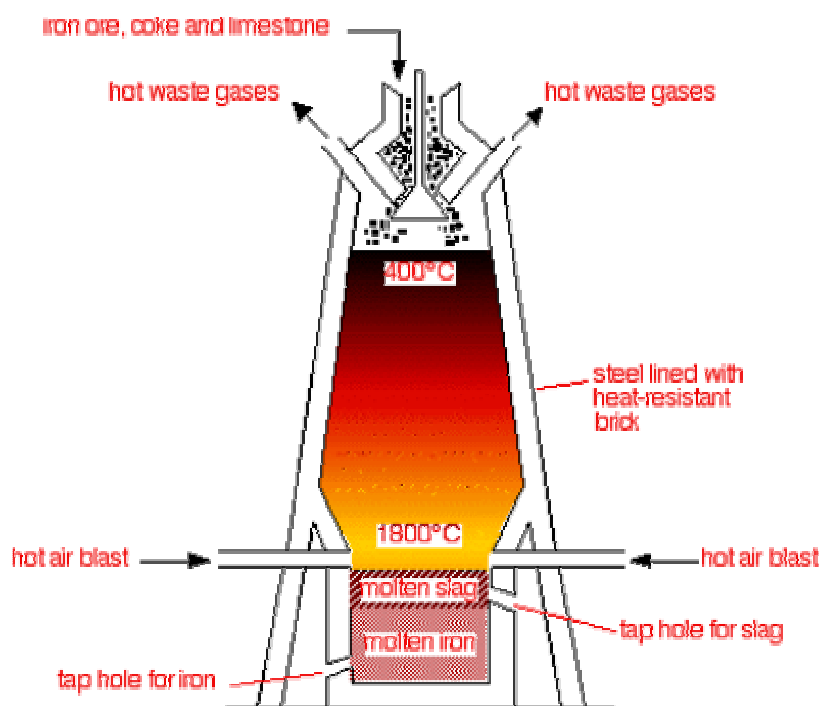
### Introduction

- The common ores of iron are both iron oxides, and these can be reduced to iron by heating them with carbon in the form of coke. Coke is produced by heating coal in the absence of air.
- Coke is cheap and provides both the reducing agent for the reaction and also the heat source.

### Iron ores

- The most commonly used iron ores are haematite,  $\text{Fe}_2\text{O}_3$ , and magnetite,  $\text{Fe}_3\text{O}_4$ .

### The Blast Furnace



### The heat source

- The air blown into the bottom of the furnace is heated using the hot waste gases from the top. Heat energy is valuable, and it is important not to waste any.
- The coke (essentially impure carbon) burns in the blast of hot air to form carbon dioxide - a strongly exothermic reaction. This reaction is the main source of heat in the furnace.



### The reduction of the ore

- At the high temperature at the bottom of the furnace, carbon dioxide reacts with carbon to produce carbon monoxide.



- It is the carbon monoxide which is the main reducing agent in the furnace.



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In the hotter parts of the furnace, the carbon itself also acts as a reducing agent. Notice that at these temperatures, the other product of the reaction is carbon monoxide, not carbon dioxide.



The temperature of the furnace is hot enough to melt the iron which trickles down to the bottom where it can be tapped off.

### **The function of the limestone**

Iron ore isn't pure iron oxide - it also contains an assortment of rocky material. This wouldn't melt at the temperature of the furnace, and would eventually clog it up. The limestone is added to convert this into slag which melts and runs to the bottom.

The heat of the furnace decomposes the limestone to give calcium oxide.



This is an endothermic reaction, absorbing heat from the furnace. It is therefore important not to add too much limestone because it would otherwise cool the furnace.

Calcium oxide is a basic oxide and reacts with acidic oxides such as silicon dioxide present in the rock. Calcium oxide reacts with silicon dioxide to give calcium silicate.



The calcium silicate melts and runs down through the furnace to form a layer on top of the molten iron. It can be tapped off from time to time as slag.

Slag is used in road making and as "slag cement" - a final ground slag which can be used in cement, often mixed with Portland cement.

### **Cast iron**

The molten iron from the bottom of the furnace can be used as cast iron.

Cast iron is very runny when it is molten and doesn't shrink much when it solidifies. It is therefore ideal for making castings - hence its name. However, it is very impure, containing about 4% of carbon. This carbon makes it very hard, but also very brittle. If you hit it hard, it tends to shatter rather than bend or dent.

Cast iron is used for things like manhole covers, guttering and drainpipes, cylinder blocks in car engines, and very heavy cookware.

## Steel

Most of the molten iron from a Blast Furnace is used to make one of a number of types of steel.

### **Steel-making: the basic oxygen process**

Impurities in the iron from the Blast Furnace include carbon, sulphur, phosphorus and silicon. These have to be removed.

#### **Removal of sulphur**

Sulphur has to be removed first in a separate process. Magnesium powder is blown through the molten iron and the sulphur reacts with it to form magnesium sulphide. This forms a slag on top of the iron and can be removed.



#### **Removal of carbon**

The still impure molten iron is mixed with scrap iron (from recycling) and oxygen is blown on to the mixture. The oxygen reacts with the remaining impurities to form various oxides.

The carbon forms carbon monoxide. Since this is a gas it removes itself from the iron!

This carbon monoxide can be cleaned and used as a fuel gas.

Elements like phosphorus and silicon react with the oxygen to form acidic oxides. These are removed using quicklime (calcium oxide) which is added to the furnace during the oxygen blow. They react to form compounds such as calcium silicate or calcium phosphate which form a slag on top of the iron.

### **Types of iron and steel**

#### ➤ **Wrought iron**

If all the carbon is removed from the iron to give high purity iron, it is known as wrought iron. Wrought iron is quite soft and easily worked and has little structural strength. It was once used to make decorative gates and railings, but these days mild steel is normally used instead.

#### ➤ **Mild steel**

Mild steel is iron containing up to about 0.25% of carbon. The presence of the carbon makes the steel stronger and harder than pure iron. The higher the percentage of carbon, the harder the steel becomes.

Mild steel is used for lots of things - nails, wire, car bodies, ship building, girders and bridges amongst others.

#### ➤ **High carbon steel**

High carbon steel contains up to about 1.5% of carbon. The presence of the extra carbon makes it very hard, but it also makes it more brittle. High carbon steel is used for cutting tools and masonry nails (nails designed to be driven into concrete blocks or brickwork without bending). You have to be careful with high carbon steel because it tends to fracture rather than bend if you mistreat it.

➤ **Special steels**

These are iron alloyed with other metals. For example:

	<b>iron mixed with</b>	<b>special properties</b>	<b>uses include</b>
stainless steel	chromium and nickel	resists corrosion	cutlery, cooking utensils, kitchen sinks, industrial equipment for food and drink processing
titanium steel	titanium	withstands high temperatures	gas turbines, spacecraft
manganese steel	manganese	very hard	rock-breaking machinery, some railway track (e.g. points), military helmets

**Some environmental considerations**

Environmental problems in mining and transporting the raw materials

- Loss of landscape due to mining, processing and transporting the iron ore, coke and limestone.
- Noise and air pollution (greenhouse effect, acid rain) involved in these operations.

**Extracting iron from the ore**

- Loss of landscape due to the size of the chemical plant needed.
- Noise.
- Atmospheric pollution from the various stages of extraction. For example: carbon dioxide (greenhouse effect); carbon monoxide (poisonous); sulphur dioxide from the sulphur content of the ores (poisonous, acid rain).
- Disposal of slag, some of which is just dumped.
- Transport of the finished iron.

**Recycling**

- Saving of raw materials and energy by not having to first extract the iron from the ore.
- Avoiding the pollution problems in the extraction of iron from the ore.
- Not having to find space to dump the unwanted iron if it wasn't recycled.
- Energy and pollution costs in collecting and transporting the recycled iron to the steel works.

## TITANIUM

The uses of titanium and its extraction from the ore, rutile.

### Introduction

- Titanium is corrosion resistant, very strong and has a high melting point. It has a relatively low density (about 60% that of iron). It is also the tenth most commonly occurring element in the Earth's crust. That all means that titanium should be a really important metal for all sorts of engineering applications.
- In fact, it is very expensive and only used for rather specialised purposes.

### Uses of titanium

- In the aerospace industry - for example in aircraft engines and air frames;
- Replacement hip joints;
- Pipes, etc, in the nuclear, oil and chemical industries where corrosion is likely to occur.

### Why is titanium so expensive?

Titanium is very expensive because it is awkward to extract from its ores - for example, from rutile,  $\text{TiO}_2$ .

### You can't use carbon reduction

Titanium can't be extracted by reducing the ore using carbon as a cheap reducing agent. The problem is that titanium forms a carbide,  $\text{TiC}$ , if it is heated with carbon, so you don't get the pure metal that you need. The presence of the carbide makes the metal very brittle.

That means that you have to use an alternative reducing agent. In the case of titanium, the reducing agent is either sodium or magnesium. Both of these would, of course, first have to be extracted from their ores by expensive processes.

### Other problems

- The titanium is produced by reacting titanium(IV) chloride,  $\text{TiCl}_4$  - NOT the oxide - with either sodium or magnesium. That means that you first have to convert the oxide into the chloride. That in turn means that you have the expense of the chlorine as well as the energy costs of the conversion.
- Titanium(IV) chloride reacts violently with water. Handling it therefore needs care.
- Traces of oxygen or nitrogen in the titanium tend to make the metal brittle. The reduction has to be carried out in an inert argon atmosphere rather than in air. That also adds to costs.
- High temperatures are needed in both stages of the reaction.
- Titanium is made by a batch process. In the production of iron, for example, there is a continuous flow through the Blast Furnace. Iron ore and coke and limestone are added to the top, and iron and slag removed from the bottom. This is a very efficient way of making something.
- With titanium, however, you make it one batch at a time. Titanium(IV) chloride is heated with sodium or magnesium to produce titanium. The titanium is then separated from the waste products, and an entirely new reaction is set up in the same reactor. This is a slow and inefficient way of doing things.

### **Titanium extraction**

Conversion of titanium(IV) oxide,  $\text{TiO}_2$ , into titanium(IV) chloride,  $\text{TiCl}_4$

The ore rutile (impure titanium(IV) oxide) is heated with chlorine and coke at a temperature of about  $900^\circ\text{C}$ .



Other metal chlorides are formed as well because of other metal compounds in the ore. Very pure liquid titanium(IV) chloride can be separated from the other chlorides by fractional distillation under an argon or nitrogen atmosphere, and is stored in totally dry tanks.

### **Reduction of the titanium(IV) chloride**

#### **Reduction by sodium**

This is the method which is used in the UK.

The titanium(IV) chloride is added to a reactor in which very pure sodium has been heated to about  $550^\circ\text{C}$  - everything being under an inert argon atmosphere. During the reaction, the temperature increases to about  $1000^\circ\text{C}$ .



After the reaction is complete, and everything has cooled (several days in total - an obvious inefficiency of the batch process), the mixture is crushed and washed with dilute hydrochloric acid to remove the sodium chloride.

#### **Reduction by magnesium**

This is the method used in the rest of the world.

The method is similar to using sodium, but this time the reaction is:



The magnesium chloride is removed from the titanium by distillation under very low pressure at a high temperature.

## ALUMINIUM

### Extracting aluminium from bauxite

#### Introduction

Aluminium is too high in the electrochemical series (reactivity series) to extract it from its ore using carbon reduction. The temperatures needed are too high to be economic. Instead, it is extracted by electrolysis. The ore is first converted into pure aluminium oxide by the Bayer Process, and this is then electrolysed in solution in molten cryolite - another aluminium compound. The aluminium oxide has too high a melting point to electrolyse on its own.

#### Aluminium ore

The usual aluminium ore is bauxite. Bauxite is essentially an impure aluminium oxide. The major impurities include iron oxides, silicon dioxide and titanium dioxide. Purifying the aluminium oxide - the Bayer Process

#### Reaction with sodium hydroxide solution

Crushed bauxite is treated with moderately concentrated sodium hydroxide solution. The concentration, temperature and pressure used depend on the source of the bauxite and exactly what form of aluminium oxide it contains. Temperatures are typically from 140°C to 240°C; pressures can be up to about 35 atmospheres.

High pressures are necessary to keep the water in the sodium hydroxide solution liquid at temperatures above 100°C. The higher the temperature, the higher the pressure needed. With hot concentrated sodium hydroxide solution, aluminium oxide reacts to give a solution of sodium tetrahydroxoaluminate.



The impurities in the bauxite remain as solids. For example, the other metal oxides present tend not to react with the sodium hydroxide solution and so remain unchanged. Some of the silicon dioxide reacts, but goes on to form a sodium aluminosilicate which precipitates out.

All of these solids are separated from the sodium tetrahydroxoaluminate solution by filtration. They form a "red mud" which is just stored in huge lagoons.

#### Precipitation of aluminium hydroxide

The sodium tetrahydroxoaluminate solution is cooled, and "seeded" with some previously produced aluminium hydroxide. This provides something for the new aluminium hydroxide to precipitate around.



#### Formation of pure aluminium oxide

Aluminium oxide (sometimes known as alumina) is made by heating the aluminium hydroxide to a temperature of about 1100 - 1200°C.

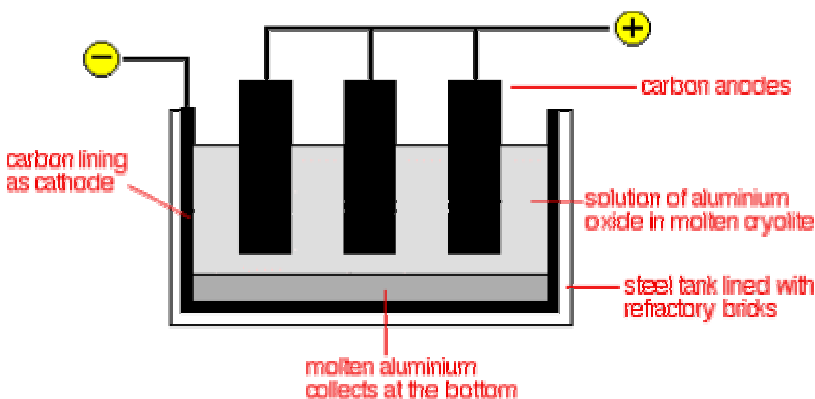


Conversion of the aluminium oxide into aluminium by electrolysis

The aluminium oxide is electrolysed in solution in molten cryolite,  $\text{Na}_3\text{AlF}_6$ . Cryolite is another aluminium ore, but is rare and expensive, and most is now made chemically.

### The electrolysis cell

The diagram shows a very simplified version of an electrolysis cell.



Although the carbon lining of the cell is labelled as the cathode, the effective cathode is mainly the molten aluminium that forms on the bottom of the cell.

Molten aluminium is syphoned out of the cell from time to time, and new aluminium oxide added at the top.

The cell operates at a low voltage of about 5 - 6 volts, but at huge currents of 100,000 amps or more. The heating effect of these large currents keeps the cell at a temperature of about 1000°C.

### The electrode reactions

Aluminium is released at the cathode. Aluminium ions are reduced by gaining 3 electrons.



Oxygen is produced initially at the anode.



However, at the temperature of the cell, the carbon anodes burn in this oxygen to give carbon dioxide and carbon monoxide.

Continual replacement of the anodes is a major expense.

### Economic considerations

- The high cost of the process because of the huge amounts of electricity it uses. This is so high because to produce 1 mole of aluminium which only weighs 27 g you need 3 moles of electrons. You are having to add a lot of electrons (because of the high charge on the ion) to produce a small mass of aluminium (because of its low relative atomic mass).
- Energy and material costs in constantly replacing the anodes.
- Energy and material costs in producing the cryolite, some of which gets lost during the electrolysis.

### Environmental problems in mining and transporting the bauxite

- Loss of landscape due to mining, processing and transporting the bauxite.
- Noise and air pollution (greenhouse effect, acid rain) involved in these operations.



### **Extracting aluminium from the bauxite**

- Loss of landscape due to the size of the chemical plant needed, and in the production and transport of the electricity.
- Noise.
- Atmospheric pollution from the various stages of extraction. For example: carbon dioxide from the burning of the anodes (greenhouse effect); carbon monoxide (poisonous); fluorine (and fluorine compounds) lost from the cryolite during the electrolysis process (poisonous).
- Pollution caused by power generation (varying depending on how the electricity is generated.)
- Disposal of red mud into unsightly lagoons.
- Transport of the finished aluminium.

### **Recycling**

- Saving of raw materials and particularly electrical energy by not having to extract the aluminium from the bauxite. Recycling aluminium uses only about 5% of the energy used to extract it from bauxite.
- Avoiding the environmental problems in the extraction of aluminium from the bauxite.
- Not having to find space to dump the unwanted aluminium if it wasn't recycled.
- Energy and pollution costs in collecting and transporting the recycled aluminium.

### **Uses of aluminium**

- Aluminium is usually alloyed with other elements such as silicon, copper or magnesium. Pure aluminium isn't very strong, and alloying it adds to its strength.
- Aluminium is especially useful because it
  - has a low density;
  - is strong when alloyed;
  - is a good conductor of electricity;
  - has a good appearance;
  - resists corrosion because of the strong thin layer of aluminium oxide on its surface. This layer can be strengthened further by anodising the aluminium.

#### **Some uses include:**

<b><u>Uses</u></b>	<b><u>Reason</u></b>
aircraft	light, strong, resists corrosion
other transport such as ships' superstructures, container vehicle bodies, tube trains (metro trains)	light, strong, resists corrosion
overhead power cables (with a steel core to strengthen them)	light, resists corrosion, good conductor of electricity
saucepans	light, resists corrosion, good appearance, good conductor of heat