



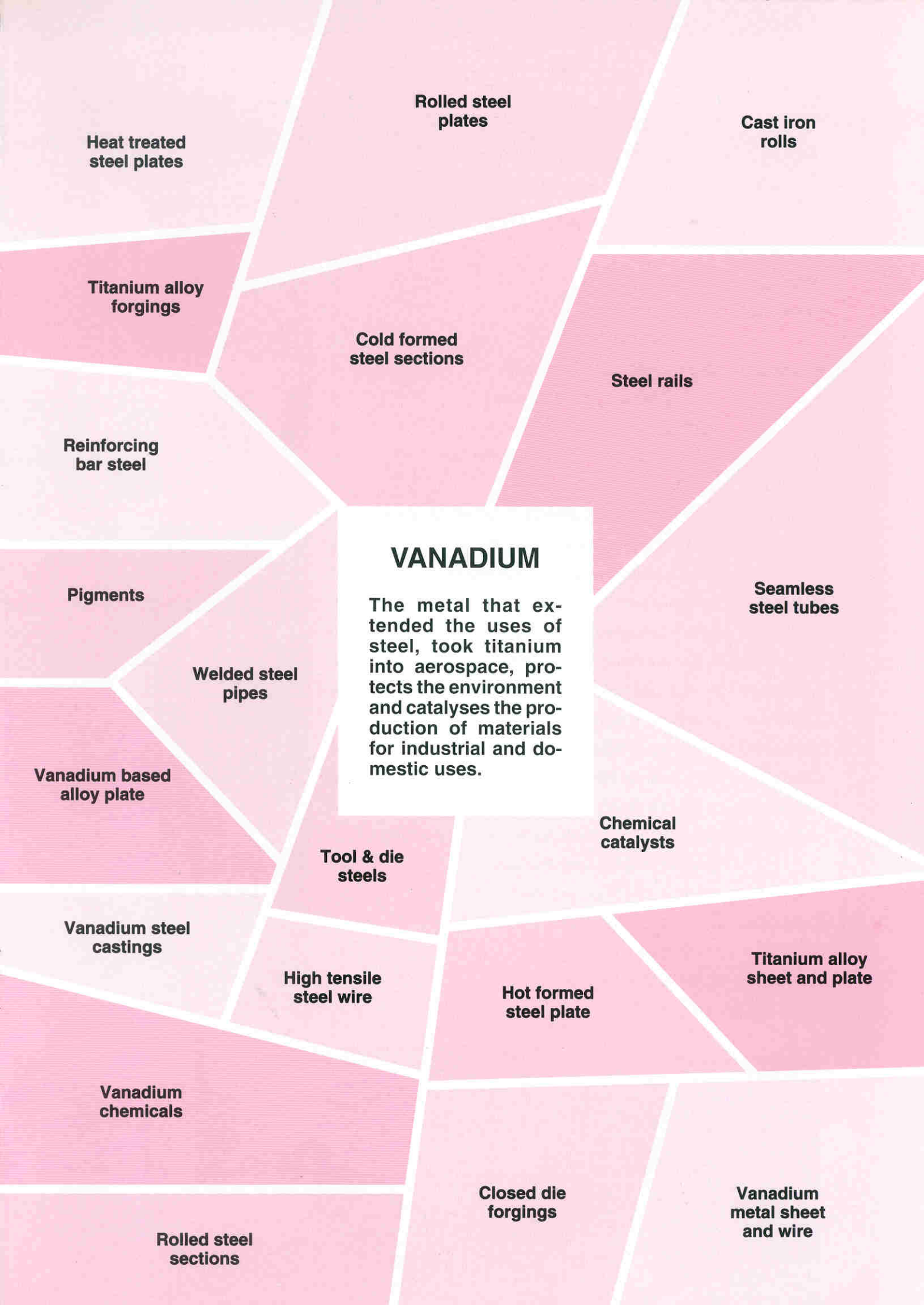
VANADIUM

VANITEC

The Vanadium International Technical Committee (VANITEC) is composed of representatives of companies involved in the mining and processing of vanadium ores for the production of vanadium oxides and slags, manufacturers of ferro-vanadium and vanadium compounds for the addition of vanadium to steel, manufacturers of alloys for adding vanadium to titanium and the producers of vanadium chemicals and catalysts.

The object of VANITEC is to promote the use of materials containing vanadium and thereby to increase its consumption. To this end it organises research on the properties of materials containing vanadium and issues various publications. These include reprints of papers from the technical press and original publications specifically prepared by its members or other organisations. In addition, it organises seminars and conferences in various parts of the world.

In 1981, at the time of the 150th anniversary of the discovery of vanadium, VANITEC endowed an award to be presented by The Institute of Metals (now The Institute of Materials) each year to the author(s) of the best published paper on materials containing vanadium.



Rolled steel plates

Cast iron rolls

Heat treated steel plates

Titanium alloy forgings

Cold formed steel sections

Steel rails

Reinforcing bar steel

VANADIUM

The metal that extended the uses of steel, took titanium into aerospace, protects the environment and catalyses the production of materials for industrial and domestic uses.

Seamless steel tubes

Pigments

Welded steel pipes

Vanadium based alloy plate

Chemical catalysts

Tool & die steels

Vanadium steel castings

High tensile steel wire

Hot formed steel plate

Titanium alloy sheet and plate

Vanadium chemicals

Closed die forgings

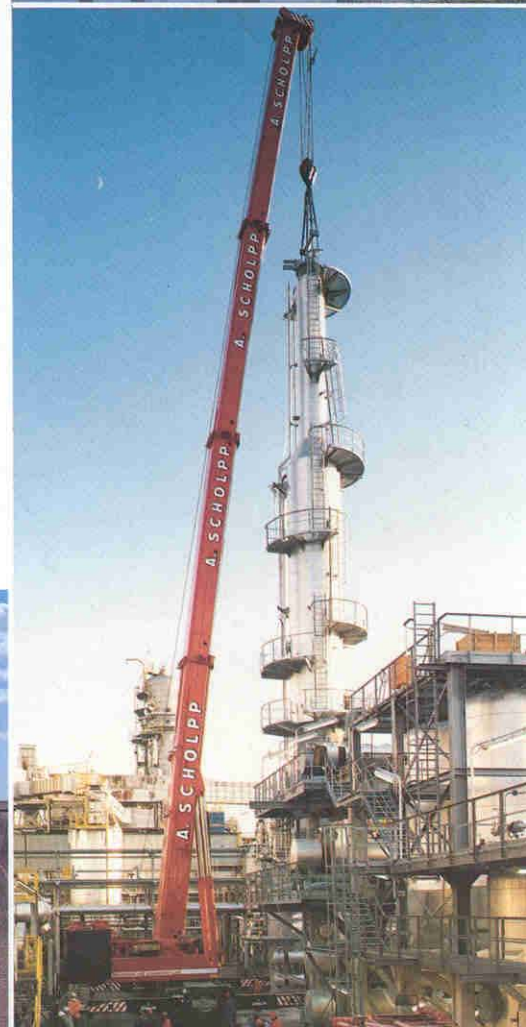
Vanadium metal sheet and wire

Rolled steel sections



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During Mining . . .



Introducing

VANADIUM

Vanadium is one of the most abundant, easily accessible and widely distributed metals in the earth's crust. Ores containing vanadium are largely available by simple opencast mining and they are economically smelted and converted into alloys for adding to steel and titanium.

Vanadium is easily converted into chemicals which have many industrial and domestic uses and which are also used in the preparation of other products.

It is an essential alloying element used in many types of steel for tools, buildings, bridges, automobiles, pipelines and machinery and for plant operating at high temperatures.

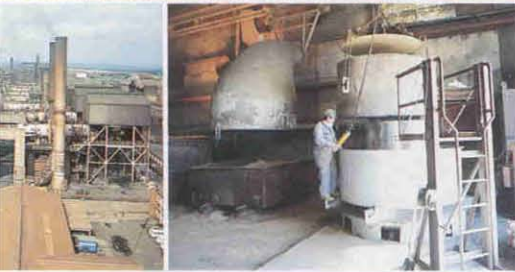
It enables titanium alloys to be used in the high temperature zones of the compressors of jet engines and in airframes.

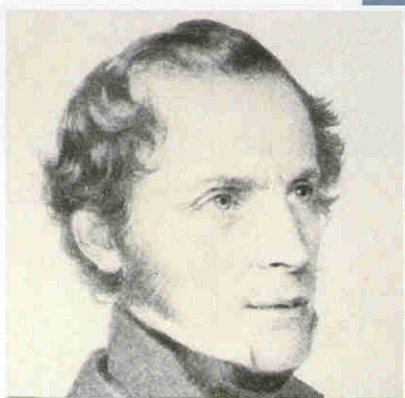
Its chemical compounds are indispensable for many industrial and domestic products ranging from spectacles and window glass, in which it prevents the passage of ultraviolet light, to decorative and industrial ceramics. A number of chemical reactions, as varied as the production of sulphuric acid, the preparation of vitamin pills, and the removal of hydrogen sulphide from natural gas and of toxic oxides of nitrogen from power plant effluent gases, are catalysed by vanadium chemicals.

Workable deposits of various ores and hydrocarbons containing vanadium are available from over 17 countries in 6 continents and its continued supply and economic production are assured for the future.

Vanadium from some steels and chemicals is recycled.

It has been supplied continuously from the beginning of the 20th century, surviving wars and political and social upheavals. It will continue to be used into the 21st century when more applications are anticipated. These include the shells of fusion reactors, steels which are to be welded by autogenous processes as well as new steels and titanium alloys for power plant and aircraft.





Iron Mine, Taberg, Sweden.

Nils Gabriel Sefström (1787 - 1845)

Sefström in his painstaking study at the laboratories of the Eckersholm iron works which obtained iron ore from the Taberg iron mountain at Falun in Sweden, separated vanadium from chromium and uranium with which it had been confused. He must have considered the automobile a fiction of the imagination, flying a dream, and space travel a fantasy. Yet his discovery, which preceded Bessemer's process for

making steel by nearly twenty years and the first production of alloy steel by Mushet by over thirty years, was essential for the development of alloy steels and titanium alloys with their remarkable properties. Without these steels and titanium alloys it would not have been possible for man to design machines which enable him to drive across the earth, fly in the sky and travel into space.

VANADIUM – WHAT IS IT?

VANADIUM – WHO FOUND IT?

Vanadium – the alloy of the century

Vanadium is a metal which was discovered by the Swedish scientist Sefström in 1831. He named it after Vanadis the Swedish Goddess of Beauty and Fertility because of the attractive brilliant colours of the chemical compounds in which it was first found.

It was well named for it has provided material for the brilliant thoughts of the fertile minds of scientists and technologists who, for over 150 years, have developed and continue to develop new materials for the benefit of humanity.

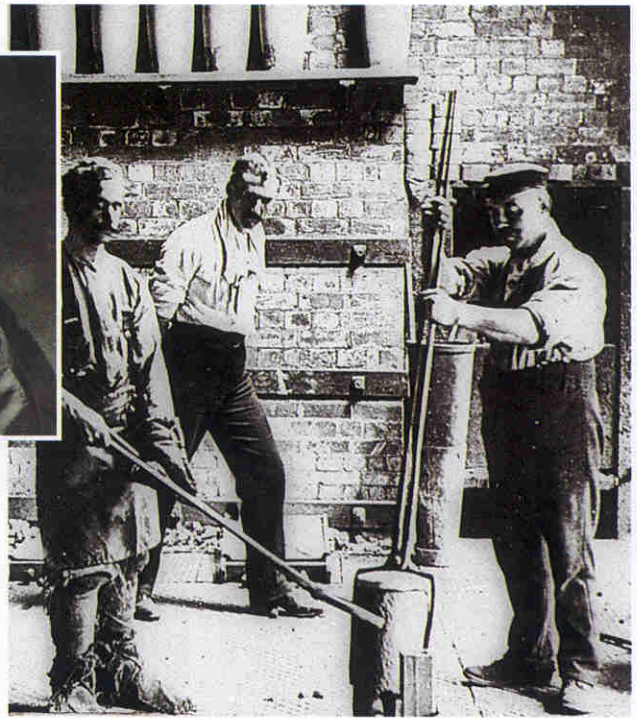


Sir Henry Roscoe (1833 - 1915)

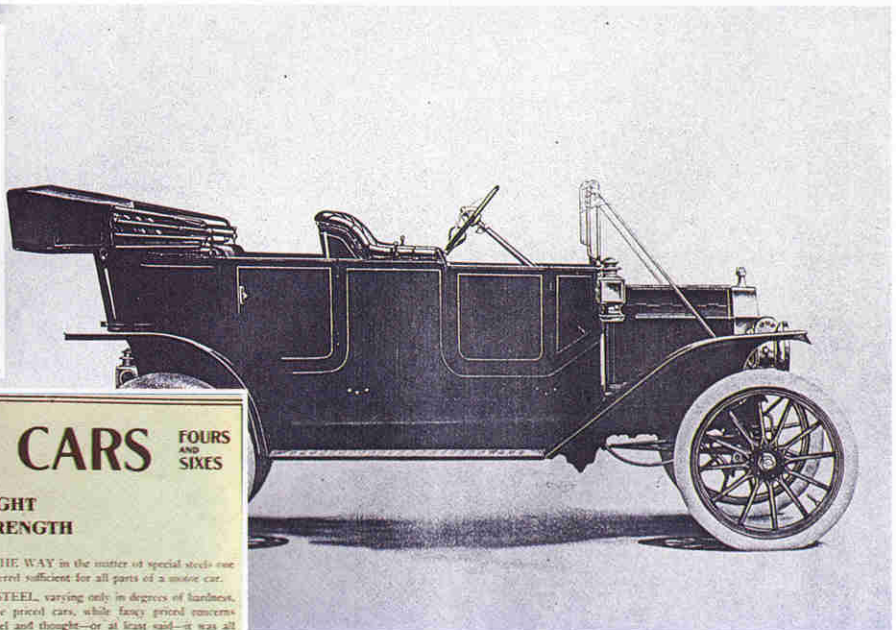
Sir Henry Roscoe, the distinguished English chemist of the 19th century, could not have conceived the consequences of isolating vanadium as a metal, which he did for the first time in 1865 while he was a Professor at Owens College in Manchester, England. He would have been amazed to know that the metal which he isolated would be the basis of alloys which would be used in plant to liberate the energy of the atom to provide light and power that would be transported as electricity which Faraday had discovered only 30 years earlier.

Professor John Oliver Arnold (1858 - 1930)

Professor Arnold, working at Sheffield College, England, in the early part of the 20th century, had no idea of the influence which his studies on the effect of vanadium on the properties of steel, which he initiated, would have on the development of steels over the next hundred years. Through the research he undertook steels have been developed with properties which make them suitable for pipelines carrying natural gas at high pressure, rails which resist the wear of heavy freight wagons on sharp curves and steep gradients and plates and sections that have twice the strength of carbon steel, enabling buildings to be constructed with over 100 floors.



Arnold's Laboratory Sheffield College, England



FORD CARS FOURS AND SIXES

**HALF THE WEIGHT
TWICE THE STRENGTH**

UNTIL FORD SHOWED THE WAY in the matter of special steels one grade of steel was considered sufficient for all parts of a motor car.

COMMERCIAL CARBON STEEL, varying only in degrees of hardness, was used in all moderate priced cars, while fancy grided steels were used "nickel chrome" steel and thought—or at least said—it was all that was desired.

NICKEL STEEL is a most deceptive metal. It shows up well in simple static tests, but it shatters like glass under sudden shock or after being subjected to vibration. Dynamically it is but little better than a good grade of carbon steel—and 85 per cent of the automobile engineer's problems are dynamic, only 15 per cent static.

VANADIUM CHROME STEEL was introduced to American metallurgy by Henry Ford. Ford was first in the world to make this rare metal in commercial quantities—40-45 ton heats. And Vanadium steel is now used, in American made cars, only in Fords.

SEVERAL DIFFERENT GRADES of Vanadium steel are used—one for front axle; another for drive shafts and rear axle; still others for crank-shafts, connecting rods, gears, springs and frames.

ANY TYRO CAN TELL VANADIUM at a glance. The micro-photographs shown on this page clearly illustrate the difference between the various steels above mentioned. The fine, even distribution of the elements—the uniformity of structure—indicate the superior quality of Vanadium, while the uneven, coarse-grained, "blotchy" ones—Nos. 5 and 6—show the uncertain structure of the best grades of carbon and nickel steels.

FORD "SIXES" AND RUNABOUTS are Vanadium Chrome Steel cars—again a year ahead.

FORD MOTOR COMPANY, 23 Fiquette Ave., Detroit, Mich.

BRANCH RETAIL STORES: New York, Philadelphia, Boston, Chicago, St. Paul, Cleveland, Detroit and other cities. Ford Motor Co., San Francisco, Oakland and Los Angeles, Distributors for California. Canadian trade supplied by Ford Motor Company of Canada, Waukegan, Ill.

1. VANADIUM CRANKSHAFT STEEL

2. VANADIUM FRAME STEEL

3. VANADIUM MESH GEAR STEEL

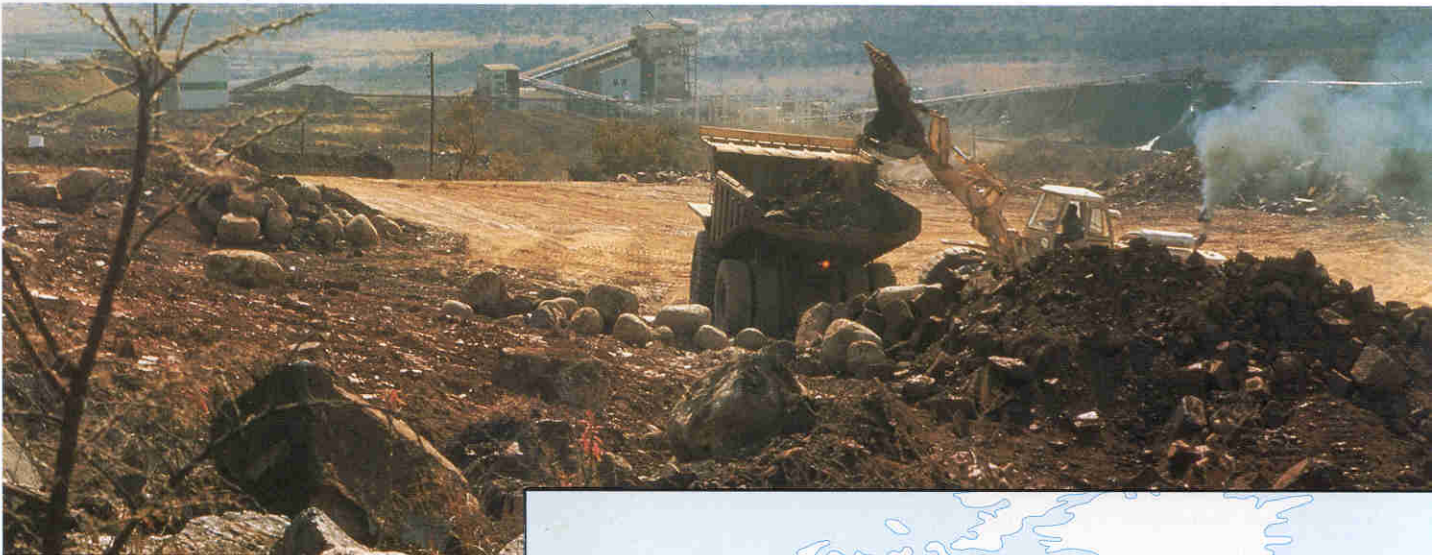
4. VANADIUM FRONT AXLE STEEL

5. CARBON AXLE STEEL

6. NICKEL AXLE STEEL

Henry Ford (1863 - 1947)

Henry Ford examined a French car in which a crankshaft made from steel produced from a Swedish iron containing vanadium resisted fracture in an accident at a race in Indianapolis. As a result he deliberately added vanadium to steels used for components in his Model 'T' and other cars. Little did he realise the magnitude of the effect his initiative would have on the adoption of vanadium steels for engineering components in the years to come.



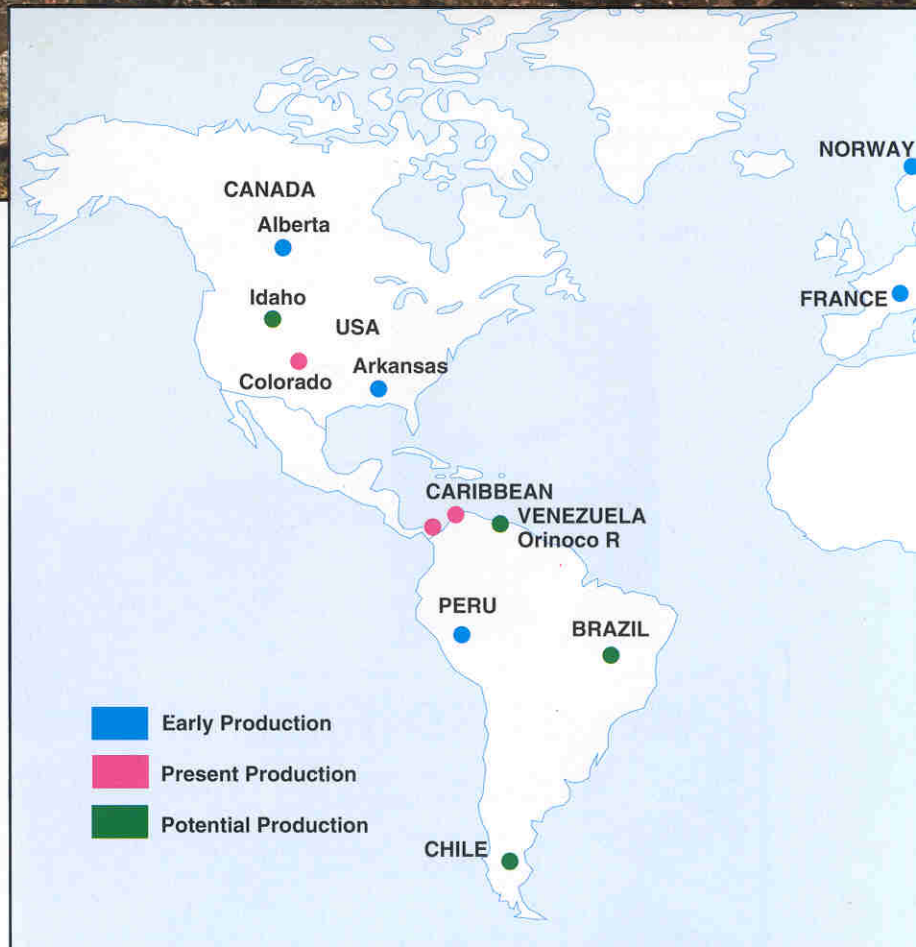
Early sources

The original supplies of vanadium came from Peru where patronite, a sulphide of vanadium, was discovered in 1906 and mined as a major source until 1955.

As early as 1899 vanadium had been found in complex uranium ore of Colorado USA where it was present in the minerals carnotite and roscoelite. These minerals were established as a commercial source of vanadium in the early part of the century and for many years vanadium was produced continuously as a by-product in the production of uranium. The decline in the demand for uranium, however, has reduced the importance of this source but significant reserves remain.

Until relatively recently vanadium was produced as a by-product in the production of lead and zinc in Namibia but this became uneconomic several years ago. For a short time it was also produced from bauxite residues arising from the production of aluminium in France.

Vanadium occurs widely in magnetites in many parts of the world and was produced as a by-product from these ores in the production of iron in Norway, Finland and for a very limited time in Australia and from aluminium clays in Arkansas USA.



Present sources

The major sources of vanadium today are the titaniferous magnetite ores of South Africa, Russia and China. In all three countries there are extensive reserves which, at the present rate of consumption, could supply the world's needs beyond the year 3 000 A.D. Some vanadium is also produced from magnetites in India.

In addition there are large

quantities of vanadium in the oils of the Caribbean and in some oils from the Middle East.

Vanadium in these oils comes to the market in various ways. It is present in the fly and boiler ashes of electric power plant where the oils are burnt and extracted from them by chemical and pyrometallurgical treatments. It is reclaimed from the nickel-molybdenum and cobalt-molybdenum catalysts on which the vanadium is deposited

VANADIUM – WHERE HAS IT COME FROM?

VANADIUM – WHERE DOES IT COME FROM?

VANADIUM – WHERE WILL IT COME FROM?

Vanadium – The abundant metal



during the oil refining processes. It is also obtained from the residues arising from a process used to desulphurise the oils and from the residues resulting from catalytic processes.

Vanadium is produced on a small scale as a by-product in the production of ferro-phosphorus in Idaho from phosphate ores containing vanadium.

It is also extracted in the form of slag as a co-product with iron in

the smelting of the iron sands in New Zealand.

Some vanadium is recycled from chemical operations where it is used as a catalyst.

The production capacity of South Africa, North America and Western Europe is of the order of 57 000 tonnes V_2O_5 a year and there is a similar capacity in Russia and China. A large proportion of the vanadium produced in Russia and China is consumed by the steel industries of those countries.

Potential sources

In addition to the extensive reserves of titaniferous magnetites containing vanadium in South Africa, Russia and China there are several other deposits of magnetites and other minerals containing vanadium from which it could be extracted in the future. There are magnetite deposits in Brazil, Chile, Western Australia and Malaysia. Oil shales and tar sands containing vanadium are present in North America and Queensland, Australia.

Vanadium in the tar sands of Alberta, Canada was extracted for a short time in 1991 and could become a source in the future.

The aluminium clays of Arkansas USA could again become a source of vanadium.

The tar-like deposits of crude oil along the shores of the Orinoco River in Venezuela contain vanadium. This could be extracted from fly and boiler ashes from electric power plant burning this fuel.



Plant producing vanadium oxides from uranium ores



Plant extracting vanadium from fly ash



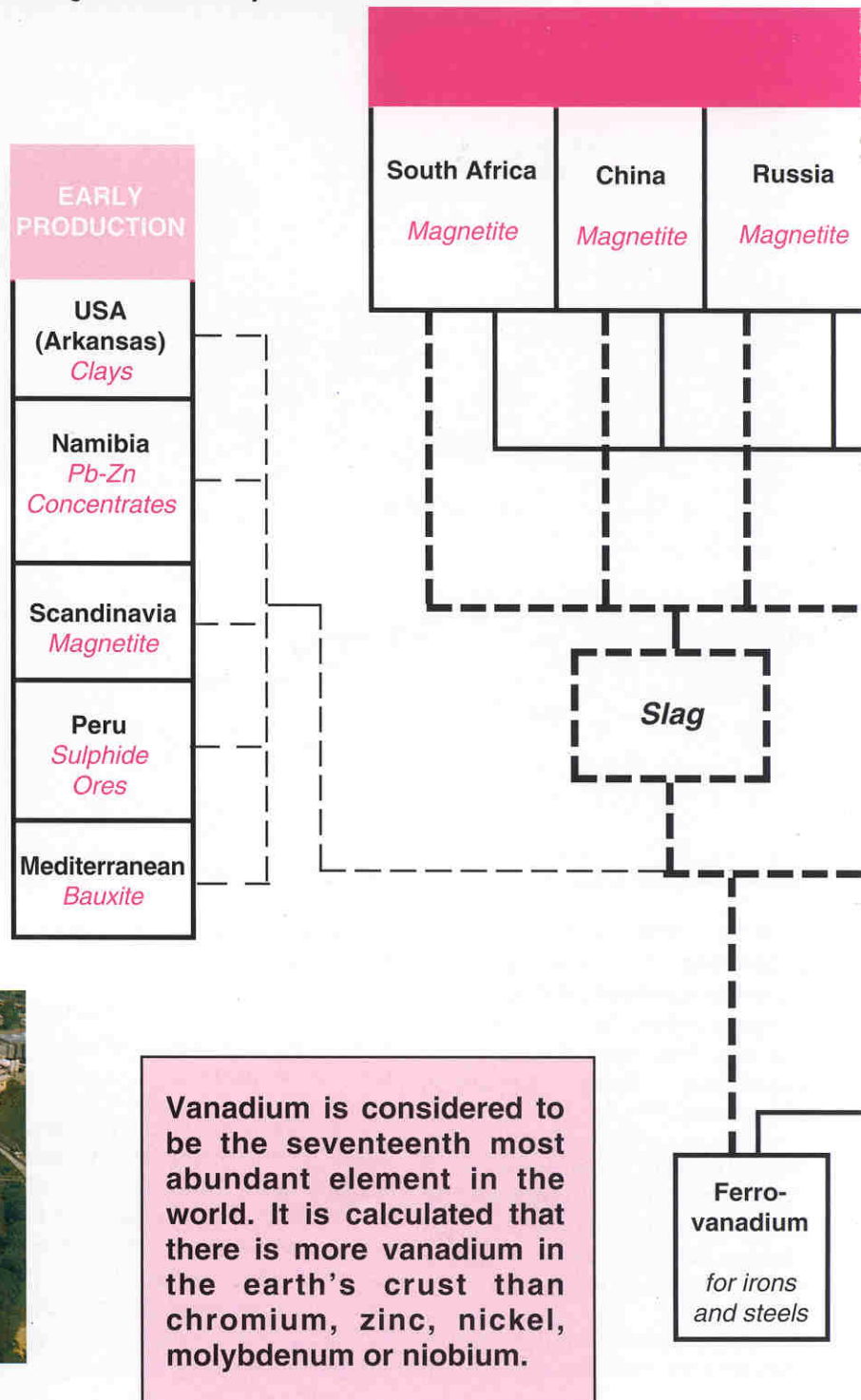
Plant recycling vanadium from spent catalysts



Plant making vanadium slag from magnetite



Plant producing vanadium oxides from slag



VANADIUM – HOW DOES IT REACH THE MARKET?

Vanadium – the universal metal

PRESENT PRODUCTION

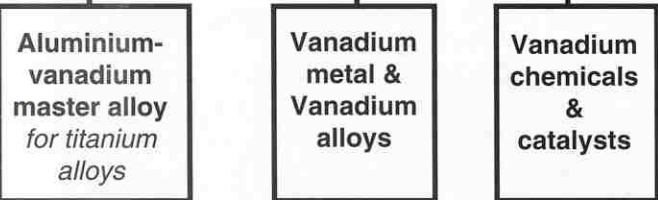
New Zealand <i>Iron sands</i>	USA (Idaho) <i>Phosphorus ores</i>	USA (Colorado) <i>Uranium ores</i>	Caribbean <i>Oil</i>	Middle East <i>Oil</i>
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POTENTIAL PRODUCTION

Malaysia <i>Magnetite</i>
Venezuela <i>Tar deposits</i>
Brazil <i>Magnetite</i>
Australia (Queensland) <i>Oil shale</i>
(W Australia) <i>Magnetite</i>
Chile <i>Magnetite</i>
Canada (Alberta) <i>Tar Sands</i>
USA (Arkansas) <i>Clays</i>



Ammonium vanadates & Vanadium oxides



Vanadium occurs in a large number of minerals widely distributed throughout the world. It has been extracted for commercial use from at least 7 of these mined in 15 countries in 6 continents.

VANADIUM – HOW IS IT PRODUCED?

Vanadium – the easily smelted metal



Plant for producing iron containing vanadium from titaniferous magnetite ore



Shaking ladle producing vanadium slag from iron

Titaniferous magnetites

Vanadium from all the magnetite ores of Russia and China, and a large proportion of the vanadium from magnetite ore in South Africa, is extracted as a co-product with iron which is converted to steel. In China and in Russia the iron is produced in a blast furnace but in South Africa, because of the high titanium content of the ore, the iron is produced by a special process involving the pre-reduction of the magnetite with powdered coal in a rotary kiln followed by reduction in a submerged arc electric furnace.

The iron from these operations contains about 1.5% vanadium which is removed as slag by low temperature treatment with oxygen. In China this is carried out by spray refining, while in South

Africa it is done in a shaking ladle and in Russia a special oxygen steel converter is used.

The slag from South Africa contains up to 25% V_2O_5 whereas the slag from China and Russia contains between 12 and 20%. The V_2O_5 is extracted from the slags by a roast-leach process in which the slags are roasted in kilns or in multi-hearth furnaces with sodium carbonate, chloride or sulphate (or lime in Russia). This produces sodium vanadates which are leached out with water. Ammonium vanadates are precipitated from this solution by addition of ammonia and sulphuric acid to control the pH. The ammonia is removed and the vanadate converted to various oxides by heating under controlled conditions

which are varied according to the oxide required. The oxides are used for the production of ferro-vanadium and vanadium-aluminium alloys required for the addition of vanadium to steel and titanium respectively. The ammonium vanadate forms the basis for the production of vanadium chemicals.

A large proportion of the slag produced in South Africa is converted to vanadium oxide in South Africa and Europe. Some South African slag is converted directly to ferro-vanadium by silico-thermic reduction in North America.

Magnetite in South Africa is also treated directly for the production of vanadium oxides by the roast-leach process.

Uranium ores of Colorado

Vanadium from the Colorado ore is extracted as a co-product with uranium at a plant in Utah. The ore is treated with sulphuric acid to dissolve the vanadium and uranium. The uranium and vanadium are separated from the liquid by solvent extraction followed by a liquid-liquid ion exchange process which separates the uranium leaving the vanadium in the acid solution. This is subsequently oxidised and removed from the organic salts with soda ash. Vanadium poly-vanadate is precipitated by the addition of ammonium sulphate.



Kiln for roasting vanadium ores

Caribbean and other oils containing vanadium

Vanadium, from oils in which it is present is obtained by various routes.

1. It is present in the coke produced in the Flexicoke process used in Venezuela for the upgrading of heavy crude oils.

The coke from this process is treated with sulphuric acid and the resulting solution with an ion exchange reaction in which ammonium vanadates are precipitated.

2. The fuels are burnt in the boilers of electric power generating plant and vanadium is left in the fly and boiler ashes.

Vanadium in these ashes is recovered by the same process as for vanadium coming from Flexicoke.

Vanadium is also recovered from the ashes after

concentration by adding it to the feed of furnaces in which slag is converted to ferro-vanadium by silicon reduction.

3. Spent nickel-molybdenum and cobalt-molybdenum catalysts are treated by chemical processes to separate the vanadium from molybdenum, cobalt and nickel to convert the vanadium to oxides.

Iron sands

Slag produced from a steel plant treating iron sands in New Zealand is exported for conversion to oxides.

Production of ferro-vanadium and aluminium-vanadium

Vanadium, like most other alloys is added to steel as a ferro-alloy. Ferro-vanadium is available in alloys containing 40, 60 or 80% vanadium. The 60 and 80% grades are mostly produced by the aluminothermic reduction of vanadium oxides in the presence of steel scrap or by direct reduction in an electric arc furnace. The 40%

grade is produced from slag and other vanadium products by the silicon reduction process.

Vanadium additions to titanium alloys are made with aluminium-vanadium master alloys which are also produced by aluminothermic reduction of vanadium oxides and followed by vacuum refining.

Ferro-vanadium production by the aluminothermic process.



Ferro-vanadium

Recycling of vanadium catalysts

Vanadium chemicals used in industrial processes, such as catalysts employed in the manufacture of sulphuric acid, can frequently

be recycled for further use. These are treated with other materials including slag, fly and boiler ashes and Flexicoke.

VANADIUM – WHAT IS SPECIAL ABOUT IT AS AN ALLOY?

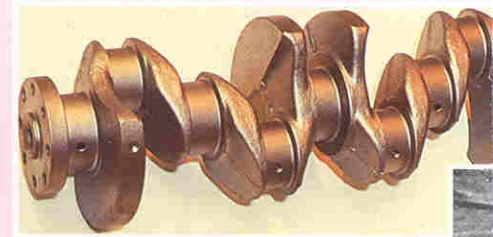
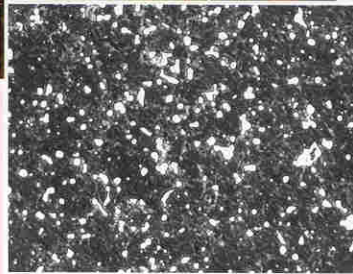
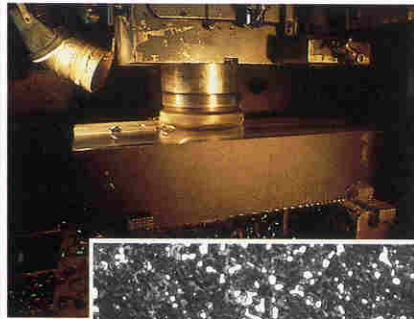
Vanadium – the versatile alloy

Vanadium in iron and steel

Vanadium can have several different effects on the microstructure and properties of steels depending on the carbon content, the content of other alloying elements and the processing conditions. In some steels it can affect the microstructure in more than one respect at the same time.

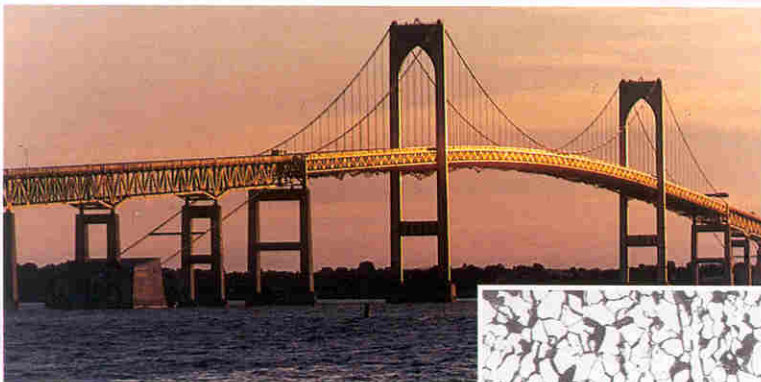
Vanadium in tool and die steels

In high-carbon steels, vanadium forms hard carbides which give the wear resistance required in dies and machine tools. The carbides do not soften at high temperatures so that the cutting edges of the tips of high-speed tools do not deteriorate when the tool is red hot. The same properties are required in the bearings of gas turbine engines for which the steels are also used.



Vanadium in forging and rail steels

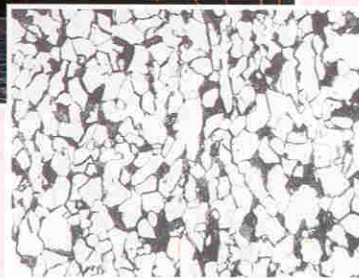
In steels used for forged automobile components and for rails, vanadium forms fine particles of vanadium carbide in the ferrite regions of the pearlite increasing the strength of the steels.



Vanadium in structural and pipeline steels

In low-carbon steels used for bridges, buildings and pipelines, vanadium forms fine precipitates at high processing temperatures which refine the grain size and thereby increase the strength and toughness at low temperatures.

At lower processing temperatures it forms finer particles which further increase the strength of steel.



Vanadium in steels operating at high temperatures

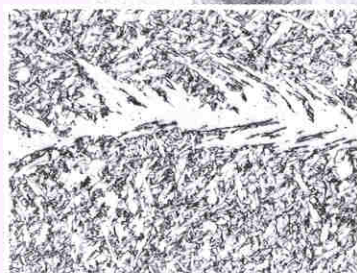
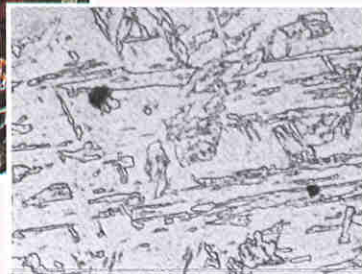
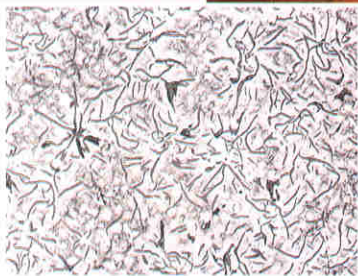
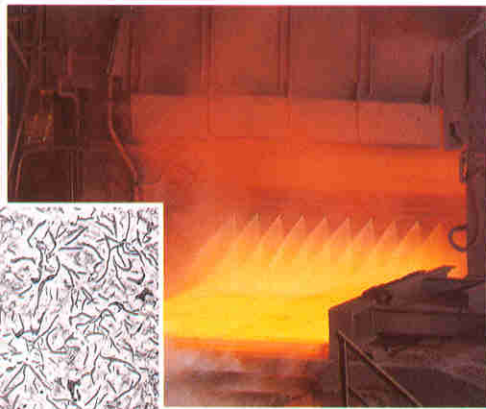
Fine precipitates of vanadium carbide are stable at temperatures above 550 °C. This means that vanadium steels can be used for turbines and steam drums in steam generating plant where the steels are maintained at high temperatures for thousands of hours without losing their strength.

Vanadium is an essential constituent in many steels and in some titanium alloys. By the use of vanadium additions high strength, toughness and other properties can be achieved.

Vanadium in Cast Iron

Vanadium when added to grey irons refines the graphite which increases the strength of the irons without loss of thermal conductivity, resistance to thermal fatigue or heat crazing.

Being a strong carbide former, vanadium tends to increase chill and the surface hardness of the irons cast in chill moulds.



Vanadium in welded steel structures

Vanadium, unlike most other alloys, stabilises the tough ferrite phase formed during rapid cooling and promotes ferrite in the heat affected zone of welds which increases the toughness of weldments at low temperatures.

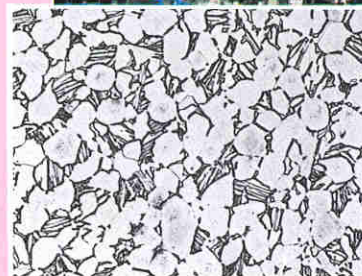
Vanadium in titanium alloys

Vanadium is soluble in titanium and stabilises the beta phase which enables the titanium to be heat treated to give higher strengths.

Vanadium-titanium alloys can be made having an all beta microstructure which enables the titanium to be cold formed.

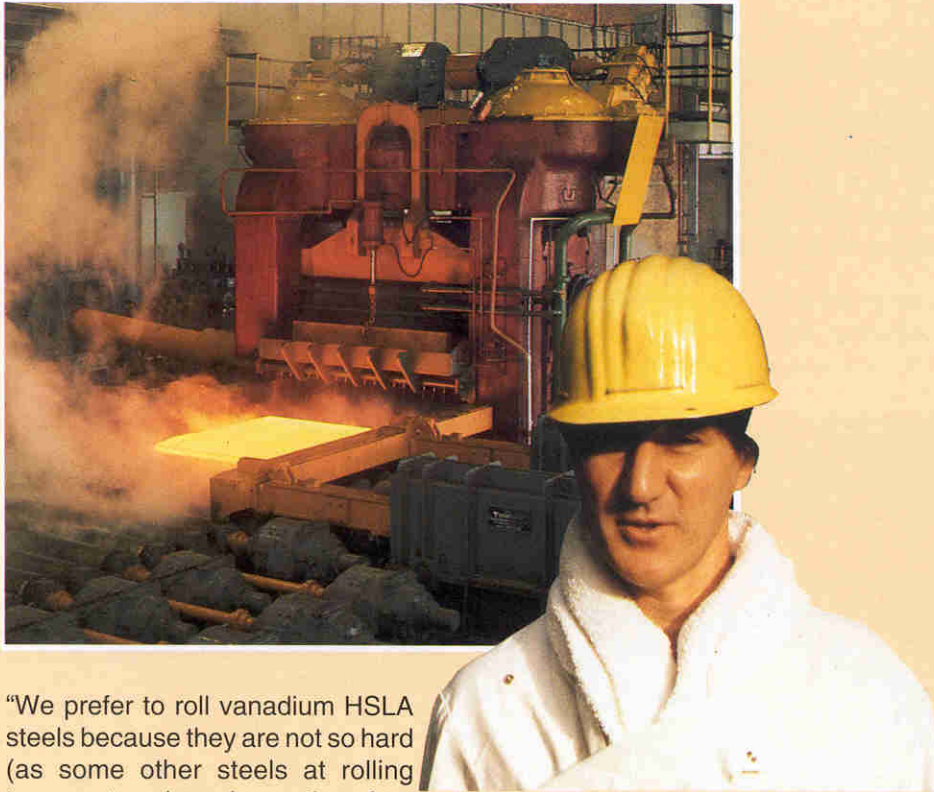
Vanadium-titanium alloys can also be hot forged to near net shape.

Vanadium-titanium alloys can be made with a coefficient of expansion close to that of glass and this makes them suitable for optical equipment.

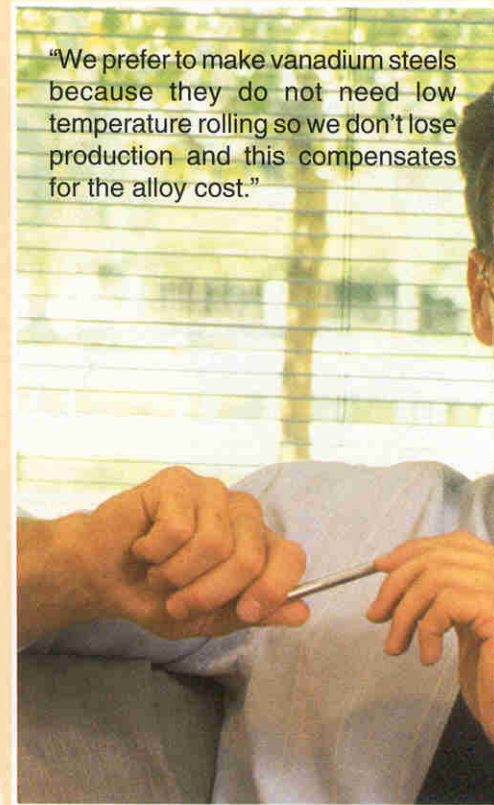


VANADIUM – WHAT DOES INDUSTRY SAY ABOUT IT?

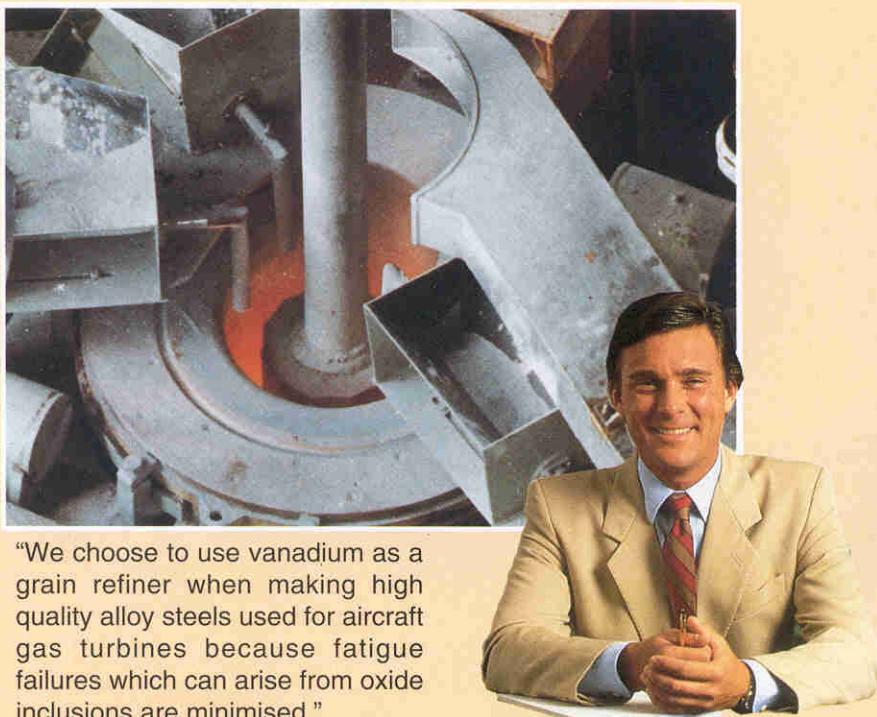
Vanadium – the alloy that practical men prefer



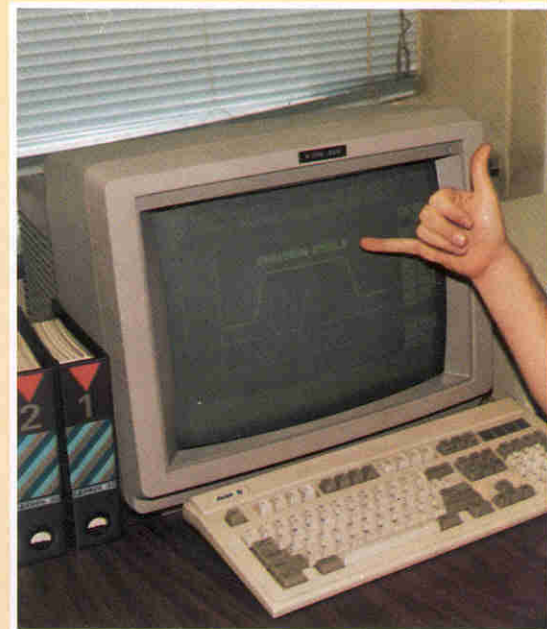
“We prefer to roll vanadium HSLA steels because they are not so hard (as some other steels at rolling temperatures) and are therefore easier to roll.”



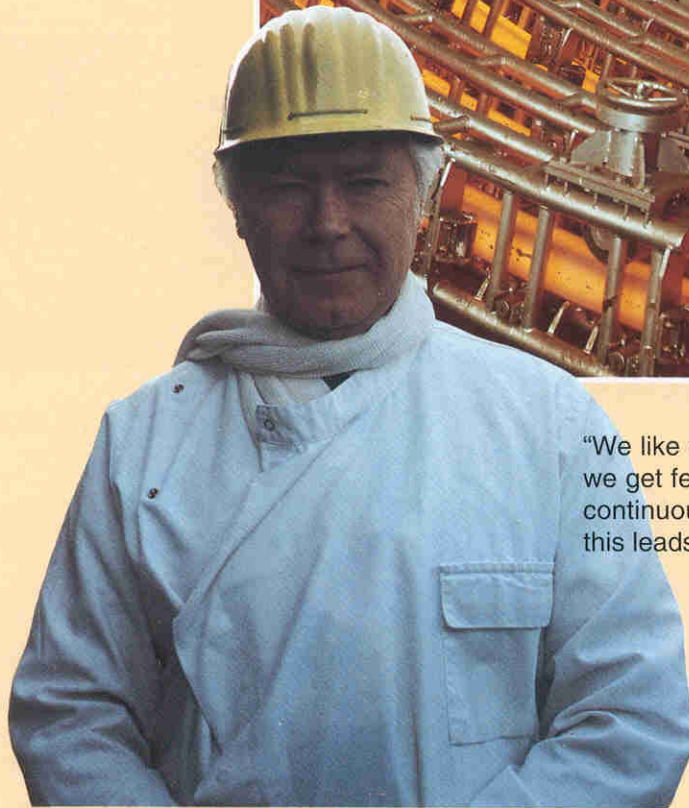
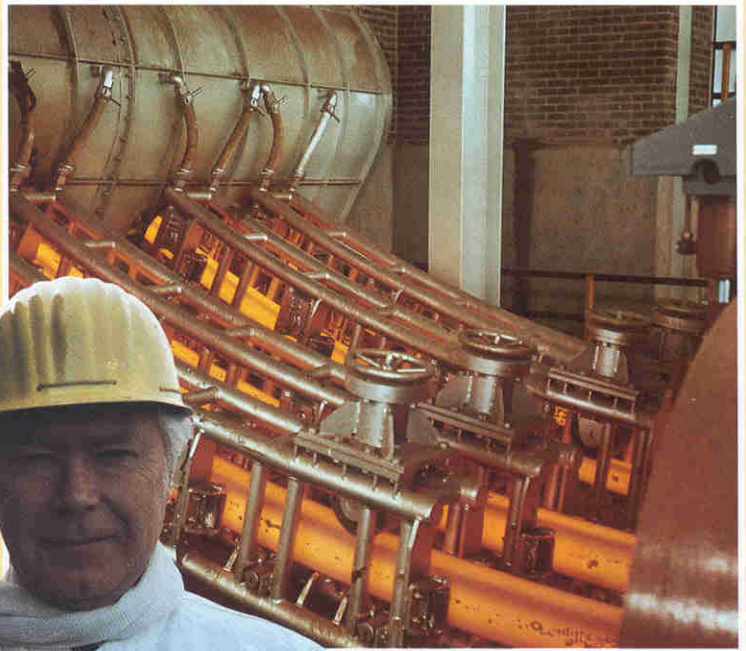
“We prefer to make vanadium steels because they do not need low temperature rolling so we don't lose production and this compensates for the alloy cost.”



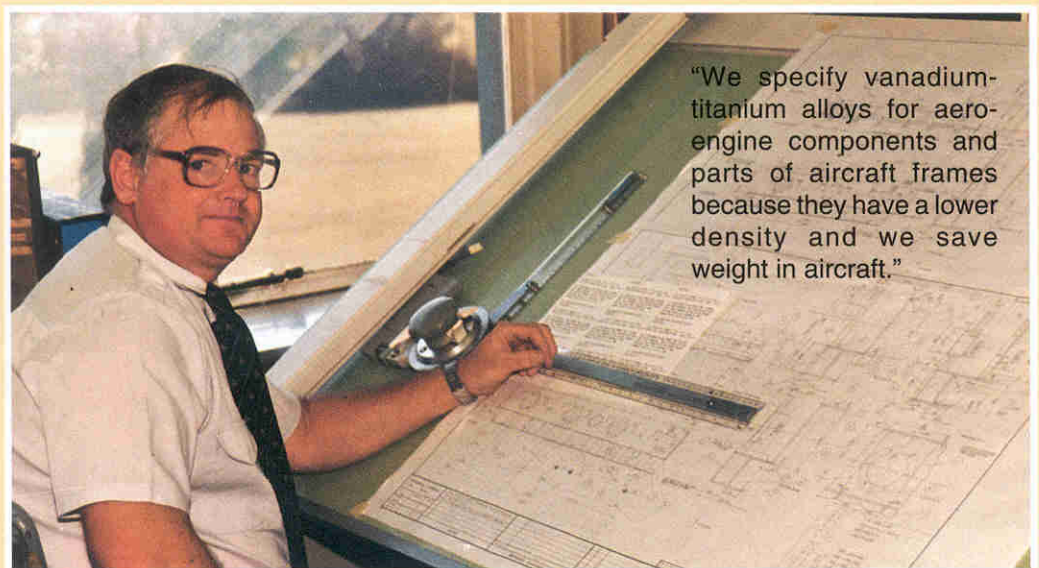
“We choose to use vanadium as a grain refiner when making high quality alloy steels used for aircraft gas turbines because fatigue failures which can arise from oxide inclusions are minimised.”



“In quality control we specify vanadium steels because (as far as their properties are concerned) they are more tolerant to variations in steel making and rolling processes.”



"We like vanadium steels because we get fewer surface cracks in the continuous casting machine and this leads to higher productivity."

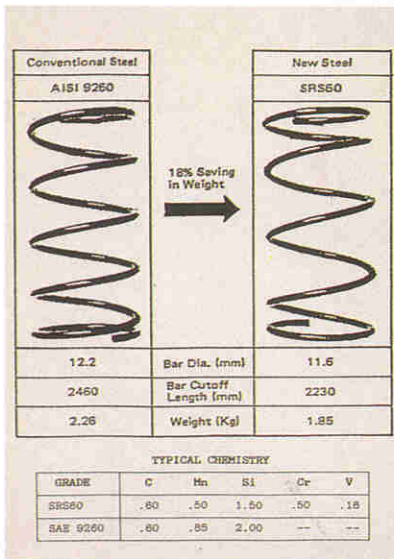


"We specify vanadium-titanium alloys for aero-engine components and parts of aircraft frames because they have a lower density and we save weight in aircraft."



Cold-formed vanadium steel chassis sections

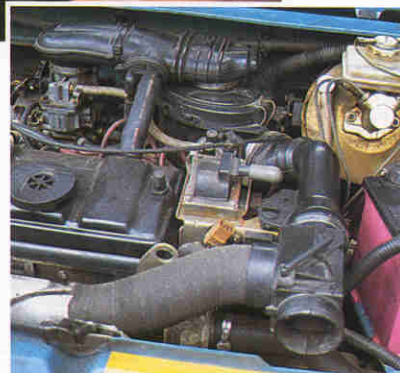
Vanadium low-sulphur, high-strength steels in the form of cold formed sections are used in the chassis of heavy trucks and trailers to keep dead weight to a minimum and payload at a maximum.



10

Vanadium steel springs

When vanadium is added to silicon spring steels the sag-resistance is increased and it is possible to reduce the size of springs. This makes a significant contribution to weight reduction and fuel economy.



4

Synthetic EPDM* rubber for hoses and seals

The hoses, belts, gaskets and seals of automobile engines which have to maintain their properties at engine temperature are made from synthetic rubber. This is made by processes involving catalytic

reactions using vanadium chloride and vanadium oxychloride.

This type of rubber is also extensively used for mouldings around the doors of automobiles and trucks.

*EPDM Ethylene Propylene Diene Monomer Rubber

VANADIUM contributes to the reliability, machinability and economic availability demanded in materials for

AUTOMOBILES AND TRUCKS

Vanadium – the alloy that increases payload and reduces fuel consumption

The automobile industry is very demanding in its selection of materials. These must be strong, reliable, machinable, resist fatigue and give the highest strength-to-weight ratio to minimise fuel consumption and be available at minimum cost. It is the ability of vanadium steels, vanadium-titanium alloys and rubber produced by vanadium catalysts to meet these and other requirements that have led to their selection for critical components in many automobiles and trucks.



3



5

Vanadium “as forged” steel crankshafts

Vanadium forged steels are widely used for crankshafts, connecting rods and steering knuckles in many automobiles and trucks. As forged they have the high strength required in these components and do not require the expensive heat treatment necessary with other steels.

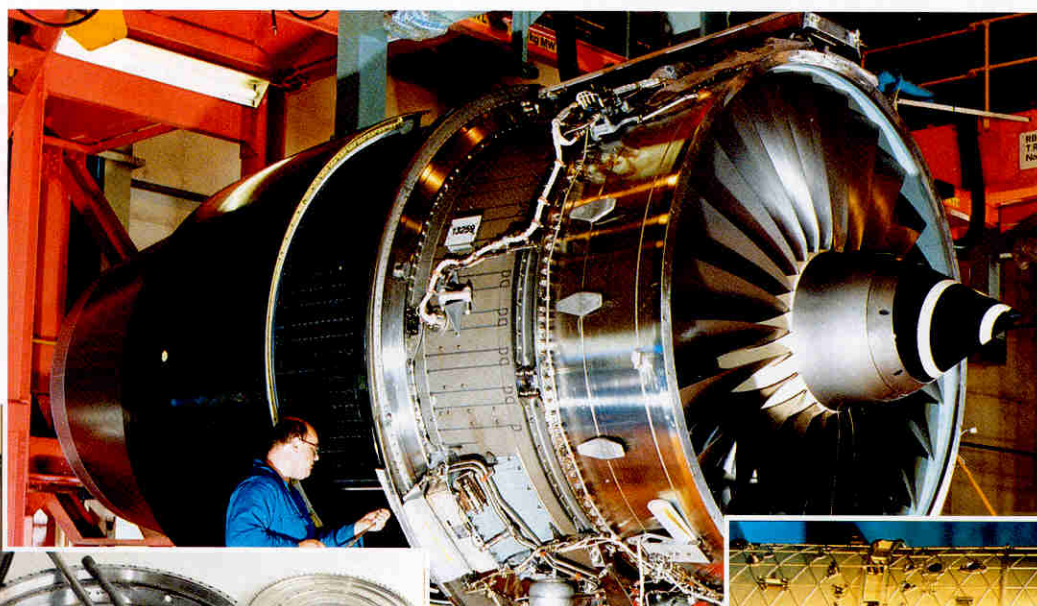
The bearing surfaces of crankshafts are hardened to give the necessary wear resistance and by choosing suitable compositions the vanadium steels can be hardened by nitriding or induction hardening.

Titanium-vanadium connecting rods

In order to decrease fuel consumption, automobile engineers endeavour to design components with minimum material and to use low density materials. Connecting rods in some automobiles are made with a titanium alloy containing 5% vanadium. This alloy has high strength, low density and a machinability enabling it to meet the severe conditions of the high-speed machining operations essential in the automobile industry.



Rolls-Royce RB211-524G Engine as used in Boeing 747-400 aircraft.

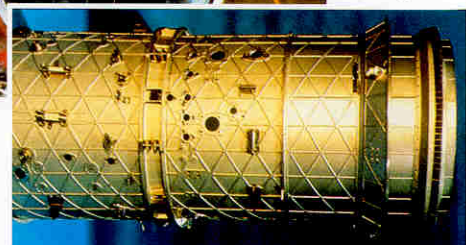


6



Turbine bearings for aircraft engine

7



9

Compressor casing



Turbine shaft

8

Steels for turbine discs, shafts and bearings

High strength and maintenance of strength at high temperatures for prolonged periods are essential in materials selected for all sections of gas turbines used in aircraft. Vanadium is added to steels to give high strength and creep resistance at temperatures above 550 °C.

The full strengthening effects of vanadium can best be achieved by the use of the Consumable Electrode Remelting Process, Vacuum Arc Remelting (VAR) and Electro

Slag Remelting (ESR). These processes both improve the cleanliness of the steel and reduce segregation; high cleanliness and low segregation being essential requirements for steels used in aero-engine gas turbines.

Vanadium is added to chromium-molybdenum steels for turbine shafts and to high chromium corrosion resisting steels for rotor discs.

The bearings for aero-engine gas turbines are frequently made of a

steel containing 1% vanadium with 18% tungsten and 4% chromium. For many decades this was the most widely used steel for high-speed machining operations because of the hardness of the primary and secondary vanadium carbides which are stable up to at least 550 °C. This hardness also provides the wear resistance required to meet the arduous conditions of bearings carrying rotor shafts rotating at high speeds at temperatures in excess of 500 °C.

VANADIUM guarantees the low density, high strength and ability to maintain strength at high operating temperatures essential for materials used in

AEROSPACE

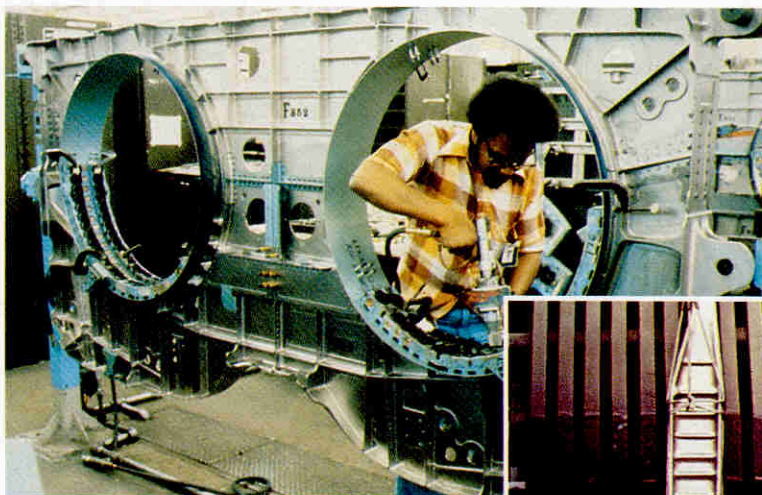
Vanadium – the alloy that took titanium into aerospace

Traditional titanium alloys for compressors and airframes

A titanium alloy containing 4% vanadium and 6% aluminium has been used very extensively for blades, discs and casings of the compressors in many designs of the aero-engine gas turbine. The heat treatment made possible by the vanadium and aluminium enables high strength alloys to be produced which maintain a high strength up to temperatures of the order of 545°C.

The high strength of the alloy has also enabled it to be used for highly stressed parts of airframes, undercarriages and the doors for the undercarriage of Concorde.

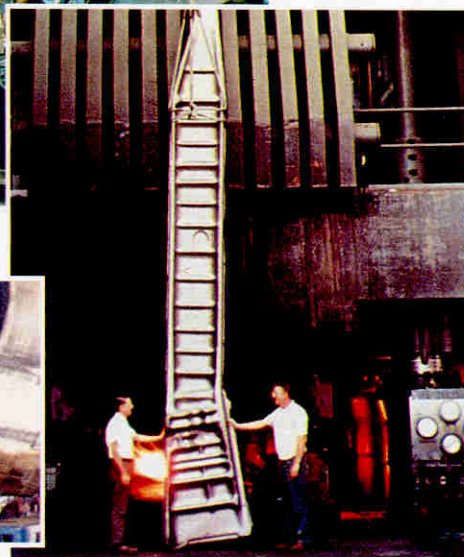
Vanadium is universally used in steels and in titanium alloys for aero-engine gas turbines and in titanium alloys used for airframes



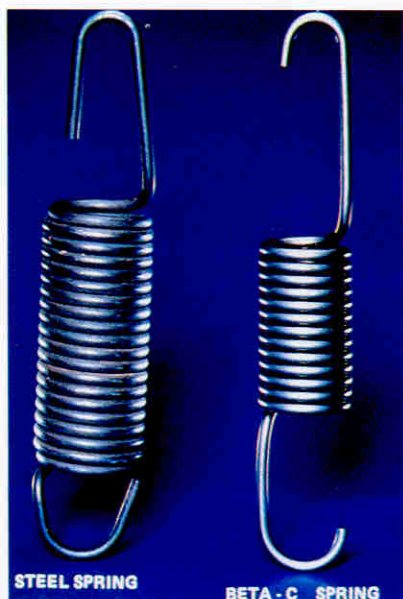
Airframe under construction



Undercarriage doors of Concorde



Landing gear of the Boeing 747 - 400 the largest component ever forged in a titanium 4% vanadium alloy



Comparison of steel (left) and titanium-vanadium alloy springs (right).

New titanium alloys

Alloys containing 8, 10 and 15% vanadium have even higher strengths.

Alloys containing 8% vanadium have been developed with high strength and high flexibility so that the lighter titanium alloys can now replace steel for springs.

The 10% vanadium alloy in the form of heat treated forgings is used in airframes particularly for the support structures in undercarriages and has been selected for this application in the Boeing 777 due to come into service in 1995.

The 15% vanadium alloy is produced as sheet with good cold working properties and has a potential for air ducting in aircraft.

All these alloys have the opportunity of making important contributions to weight reduction and the increase of fuel efficiency in aircraft of the future.



Points

Vanadium-copper steel rails are widely used on Belgium Railways for points because of their higher wear resistance.

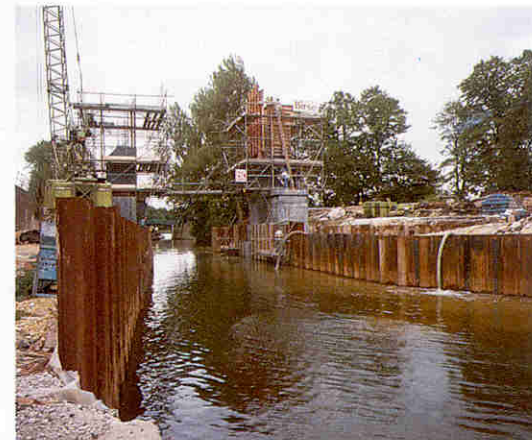
Vanadium rail steels

The addition of vanadium to rail steels can increase the tensile strength from about 700 N/mm² to over 1 200 N/mm² and thereby increase the wear resistance of the rails.

In Japan vanadium steel rails are made by a practice in which the wear-resistant surfaces are produced by surface heat treatment at the end of the rolling process.

Fully or surface hardened vanadium steel rails are used wherever severe conditions of service are found. They are extensively used on sharp curves and steep gradients including tracks carrying iron ore which is transported in large wagons having axle loads exceeding 35 tonnes.

In Russia where large tonnages of iron ore are transported over long distances, special vanadium steels are used to increase the life of the rails and reduce track maintenance.



Sheet piling

Vanadium steels supplied in the "as rolled" condition are widely used for sheet piling in docks and along river banks especially where there is a large difference between the levels of high and low tide or where large dockside buildings cause high transverse loads. By using vanadium steels which have a high strength, the thickness, weight and cost of the piling can be kept to a minimum. Vanadium also ensures good toughness in the steels, enabling them to resist fracture which could result from accidental impact from vessels in dock in cold weather.

Railway wagons

Railway wagons used for carrying bulk supplies of coal, iron ore and similar hard products require steel plates for the walls of the wagons which will resist the abrasive action of the hard materials during loading and unloading. The plates are also required to have resistance to corrosion greater than that of ordinary high strength steels. Special steels containing vanadium, chromium and phosphorus have been developed which have these properties without the disadvantages associated with high phosphorus steels and are widely used for railway wagons carrying iron ore and coal in Europe, North America and Russia.

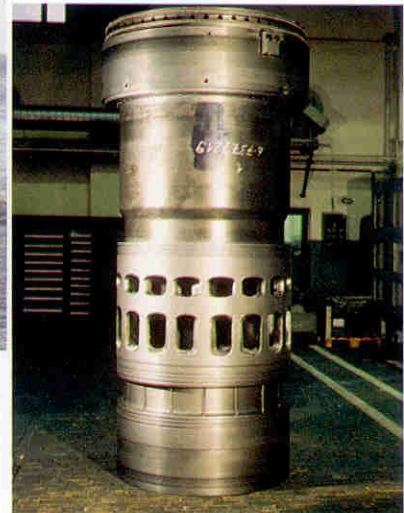
VANADIUM provides steels and titanium alloys with the strength dependability, durability and resistance to wear demanded by

RAIL AND MARINE OPERATIONS

Vanadium – the alloy that ensures wear resistance and dependability



13



Vanadium cast iron liner in Sulzers marine diesel engine

14

Vanadium steels used for high strength chains

Vanadium steels are frequently used for heavy chains made from welded bar. The vanadium refines the grain size and increases the strength and wear-resistance.

Cast iron cylinders for marine diesel engines

Vanadium is added to cast iron used for the liners of diesel engine cylinders. The vanadium forms hard vanadium carbides which resist the abrasive action of the piston materials at operating temperatures which can exceed 450°C.

Ship plates

Vanadium steels can be used for ship plates. Increasing competitiveness in the ship building industry has created a demand for steels which can be welded at high speed without the necessity to preheat the steels for avoidance of hydrogen absorption in the weld metal even when the welding is carried out in damp conditions. Accelerated cooling practices in the rolling of plates have been developed to produce high strength steels with low carbon contents free from hydrogen damage. Although other alloys can be used to provide a high strength, vanadium is often preferred as vanadium steels are free from the casting and other problems associated with alternative steels. Vanadium also promotes a microstructure in the heat affected zone of welds associated with higher toughness.



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Vanadium-titanium alloy bathysphere

Vanadium has been used together with aluminium to give the required strength in a titanium alloy used for a special bathysphere for exploration of the ocean at depths of 10 000 metres. The vessel is made as a single forging and heat treated to have a high strength in all directions an essential property for a bathysphere which has to withstand the pressures of the ocean.

For over fifty years of electric power generation, the stability of vanadium carbides at high temperature has formed the basis for the successful operation of many grades of steel used in most of the critical parts of steam turbines and boilers. During this period typical steam temperatures have increased from 480

to 565 °C enabling the efficiencies of the plants to increase from 30% to over 43%. Various types of steel have been used for headers, superheater tubes, rotors, casings and blades to resist creep, corrosion and fatigue. Vanadium has been employed in a large proportion of the steels specified in Europe,

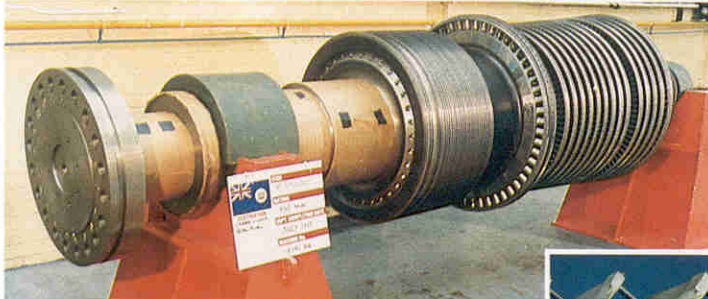
North America and other parts of the world. Attempts are continuing to increase the efficiency of electric power generation from fossil fuels by increasing steam temperatures and by other methods and in most of these developments vanadium steels play a dominant role.

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Turbine rotor

16



Turbine casing

17



18

Turbine blade tip of L.P. turbine



Rotors, discs and blades

The turbine rotors, discs and blades of a steam generating plant operate under the most severe conditions having to resist creep, fatigue and corrosion.

Steels containing 1% chromium, 0.5% molybdenum and 0.25% vanadium are widely used for the rotors of high and intermediate pressure turbines because of their high strength and creep resistance. They continue to be used in modern high pressure turbines operating at temperatures up to 565 °C and at pressures up to 166 bar. In addition to providing strength and creep resistance to the steels through the carbide precipitates, vanadium has

also replaced aluminium for grain refinement. This together with the adoption of vacuum degassing during steel-making produces cleaner steel with higher fatigue resistance. These developments have led to the manufacture of rotors for the high pressure turbines machined from monoblock forgings with considerable economy.

In some countries a steel containing 12% chromium, having higher corrosion resistance, is used for rotor forgings but the steel also contains vanadium to give stability at the high steam temperatures.

Similar 12% chromium steels are used for the turbine blades which have to resist corrosion as well as creep. In low pressure turbines they

have to resist erosion from water droplets. In these steels, strength and creep resistance is achieved by vanadium and other alloying elements. The tips of the blades in some large low pressure turbines are subject to particularly severe conditions and inserts of high-speed tool steels containing 0.5% vanadium are used.

In low pressure turbines, operating with steam temperatures below 350 °C, corrosion and erosion from water droplets are of greater importance and higher chromium and/or nickel additions are made to rotor steels. These steels also contain vanadium to give the desired heat treatment response.

VANADIUM sustains the strength of steel at high temperatures for prolonged periods demanded in

ELECTRIC POWER GENERATION

Vanadium – the alloy stable at high temperatures

Turbine casings

The casings of turbines have to resist the stresses resulting from the steam pressure at the operating temperature. They are also subject to thermal fatigue and are made as castings. They are commonly made from 0.5% chromium, 0.5% molybdenum, 0.25% vanadium steel where vanadium provides the creep resistance at elevated temperatures.



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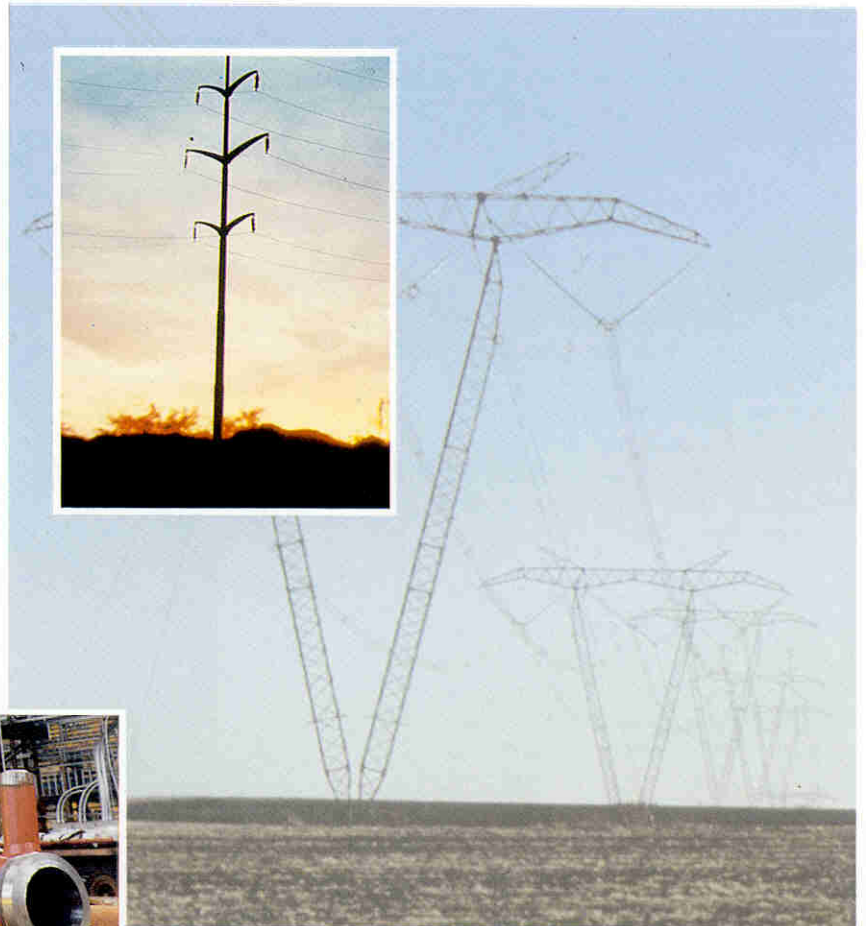
21

Steam headers, superheater tubes and drums

For many years molybdenum-vanadium and chromium-molybdenum-vanadium steels were standard materials for superheater tubes and steam headers but for a while were superseded by chromium-molybdenum steels. Today however, when steam temperatures in some stations are of the order of 580°C, 12% chromium steels with vanadium additions to provide the resistance to creep at high temperature are being adopted. The

strength of this steel at the high steam temperatures enables the wall thickness and hence the cost to be kept to a minimum.

Large steam drums which collect the steam from the boiler tubes are made from plates up to 150 mm in thickness. The steels used contain nickel, chromium and molybdenum to provide corrosion resistance but vanadium is present to give strength at the high temperatures. Such drums can involve up to 200 tonnes of steel.



Transmission towers and poles

Electric power from generating plant is carried across land to towns and industrial areas by copper or aluminium cables supported on a series of steel poles or towers. Many of the routes for the transmission of the power involve long distances along difficult and remote terrain. For ease, economy of transport and erection, it is important that the towers should be of minimum weight. Vanadium steels having yield strengths 20% higher than carbon steels are frequently used thus allowing weight reductions to be made.

Pipelines

Alongside the increasing demand of oil and gas companies for steels having higher strengths, increased low temperature toughness and a capability to be welded at higher speeds, developments have also taken place in steelmaking and rolling which have enabled higher strengths to be attained at lower carbon contents without heat treatment.

The first high strength steels were supplied in the normalised condition and vanadium was added with nitrogen to give a fine grain size and precipitation strengthening.

Special rolling processes which replaced the normalising enabled low carbon steels with increased weldability to be used for pipelines but they required vanadium to maintain the strength of the pipe especially in pipes with thicker walls. Variations have taken place in the pipe-making processes but in both the traditional and the new methods vanadium is used to maintain the strength of the pipes.

Vanadium steels were used in most of the major pipelines built in the second half of the 20th century including the Alaskan oil pipeline, the trans-European pipe bringing natural gas from the Russian Arctic to western Europe and the Northern Borders pipeline bringing natural gas from Alberta, Canada to the eastern USA.



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Pipes for transport of sour gas

A large proportion of the natural gas coming from below the sea is sour and has to be transported by pipeline to land before the hydrogen sulphide can be removed.

In order to avoid the corrosion which results from hydrogen sulphide in sour gas, lower carbon and manganese contents are used and to compensate for the resulting loss in strength vanadium is added.

The oil and gas industries have for over fifty years continuously offered challenges to the steel industry and more recently to the titanium industry for higher strength materials. Invariably, additional properties are required such as toughness at low temperatures for pipelines laid in arctic regions or special corrosion resistance for lines carrying sour gas.

The greatest developments have taken place in pipeline steels for gas transmission because an

increase in strength can enable higher pressures to be used and this dramatically reduces the cost of transporting gas. Higher strengths are also important for oil lines to reduce the wall thickness of the pipes and thus to reduce the weight of pipes and the cost of transporting the pipes to site. This is significant in lines stretching for thousands of kilometres.

Where the pipelines operate at low ambient temperatures the steels must be resistant to low



Offshore platforms

The legs of offshore platforms are welded from plate steels and in many the strength is achieved by the addition of vanadium.

In platforms built in deep water the weight of the superstructure is of critical importance and extra high strength heat treated vanadium steels are used.

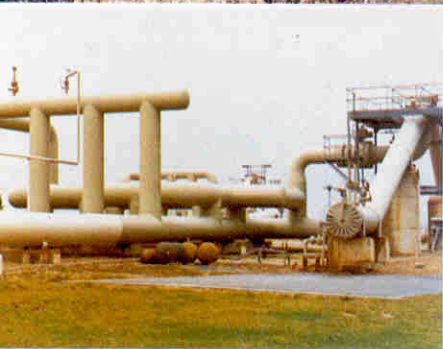
temperature brittleness. All steels must be weldable at the highest possible speeds without susceptibility to hydrogen cracking even when welded in regions of high humidity. For pipelines carrying sour gas the steels must be resistant to corrosion by hydrogen sulphide.

Vanadium is used in steels made to specifications involving various combinations of these properties for operation in many types of environment.

VANADIUM gives strength and low temperature toughness to steels and titanium alloys demanded for

OIL AND GAS PRODUCTION AND TRANSMISSION

Vanadium – the strengthening and toughening alloy



23

Pipeline valves and bends

Valves and bends in pipelines are forged and welded from plates of normalised high strength steels containing vanadium.

Vanadium-titanium alloy pipe for oil and gas wells

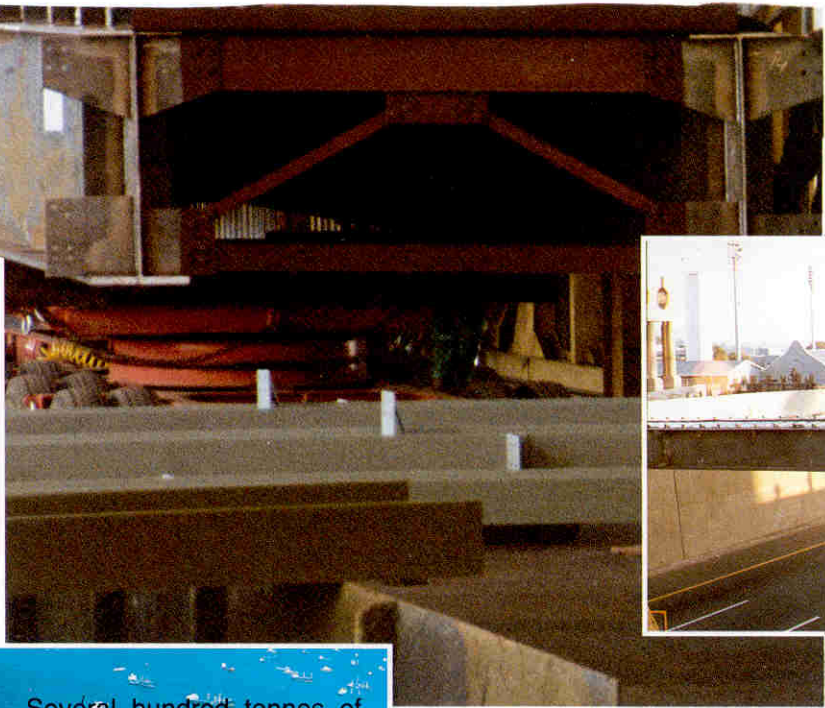
Vanadium provides the strength in pipes of titanium alloys developed to resist the severe corrosive action of sour gas and oil in some wells in North America.

Oil storage tanks

Oil storage tanks are made by welding normalised or quenched and tempered steels which depend for their strength on vanadium carbide precipitation.

Interchange bridge, Johannesburg

The bridge at the Goldenhuis interchange near Johannesburg consisting of two 30 m spans involves four girders welded from vanadium steel plate. The steel has a yield strength of 350 N/mm² and a Charpy V impact minimum of 27 J at -30 °C required by local codes to guarantee the necessary resistance to fatigue.



Central plaza, Hong Kong



Several hundred tonnes of vanadium are present in the reinforcing bars used in the construction of the numerous ferroconcrete buildings in Hong Kong including the Central Plaza — the highest building in Asia.

24



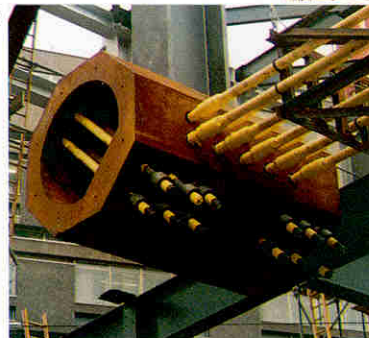
Sears building, Chicago



25

The famous Sears building in Chicago, is reputed to be the highest in the world and is made with high strength vanadium steel sections.

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High strength vanadium steel cast node

Lee House, London

Lee House straddles London Wall, one of the City of London's main thoroughfares. The tension members of the trusses across the 27 m roadway supporting an 18-storey office block are anchored in cast vanadium steel nodes each weighing up to 18 tonnes. These are the largest steel castings ever used in the building industry.

VANADIUM provides strength in steels for

BRIDGES AND BUILDINGS

Vanadium – provides strength in structural steels around the world



Vanadium is the most widely used alloying element for strengthening steels employed in buildings and bridges. It is the most effective alloy for

increasing the strength of reinforcing bars used for buildings, tunnels and bridges; it is added to bars for pre-stressed concrete structures and suspension ropes and it is a commonly adopted alloying element for strengthening steel sections. Vanadium is used alone and in combination with other alloying elements for strengthening steel plates for box girder and other types of bridge. It is added to steels designed to resist fire and earthquake and is employed to strengthen steels designed to resist the corrosive effects of weather.



Gion bridge, Sweden

The welded bridge across the river at Gion in Sweden is built with high strength "as rolled" steel plates containing vanadium and titanium.



Bridge made of weathering steel



Buildings and bridges are made with pre-stressed concrete in which steel cables are strengthened with vanadium.

Many buildings and bridges where steel is exposed to the environment are made with a steel which resists corrosion and does not require painting. High strength is achieved in these steels by additions of vanadium.

Vanadium steels are used in many types of crane, parts of drag lines, and trucks working in opencast mines and in road construction.

In cranes and in the spars of drag lines, vanadium provides the strength in rolled and heat treated sections where the maxi-

mum strength-to-weight ratio is required.

Vanadium steels are also used in universal beams and in heavy plates (over 330 mm thick) where strength and rigidity are important.

In addition vanadium steels are used for the buckets of some

drag lines enabling heavier loads to be lifted without distortion.

By suitable alloy composition and/or heat treatment, steels can be used in these machines which will resist fracture under impact loading conditions even when they are used in low temperature environments.



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Steels for heavy duty trucks

Vanadium is used in steels required to have strength, abrasion resistance and toughness in many parts of trucks especially those operating in mines and other severe environments.

By the use of vanadium steels, protection can be given to cabs of trucks where ore, coal or over-burden can fall on the cab.



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Vanadium steels also provide reinforcement to the side walls of trucks while they are being loaded.

Vanadium steels are used in the frames to enable the maximum strength-to-weight ratio to be achieved so that the maximum payload can be carried.



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VANADIUM provides the strength and toughness for

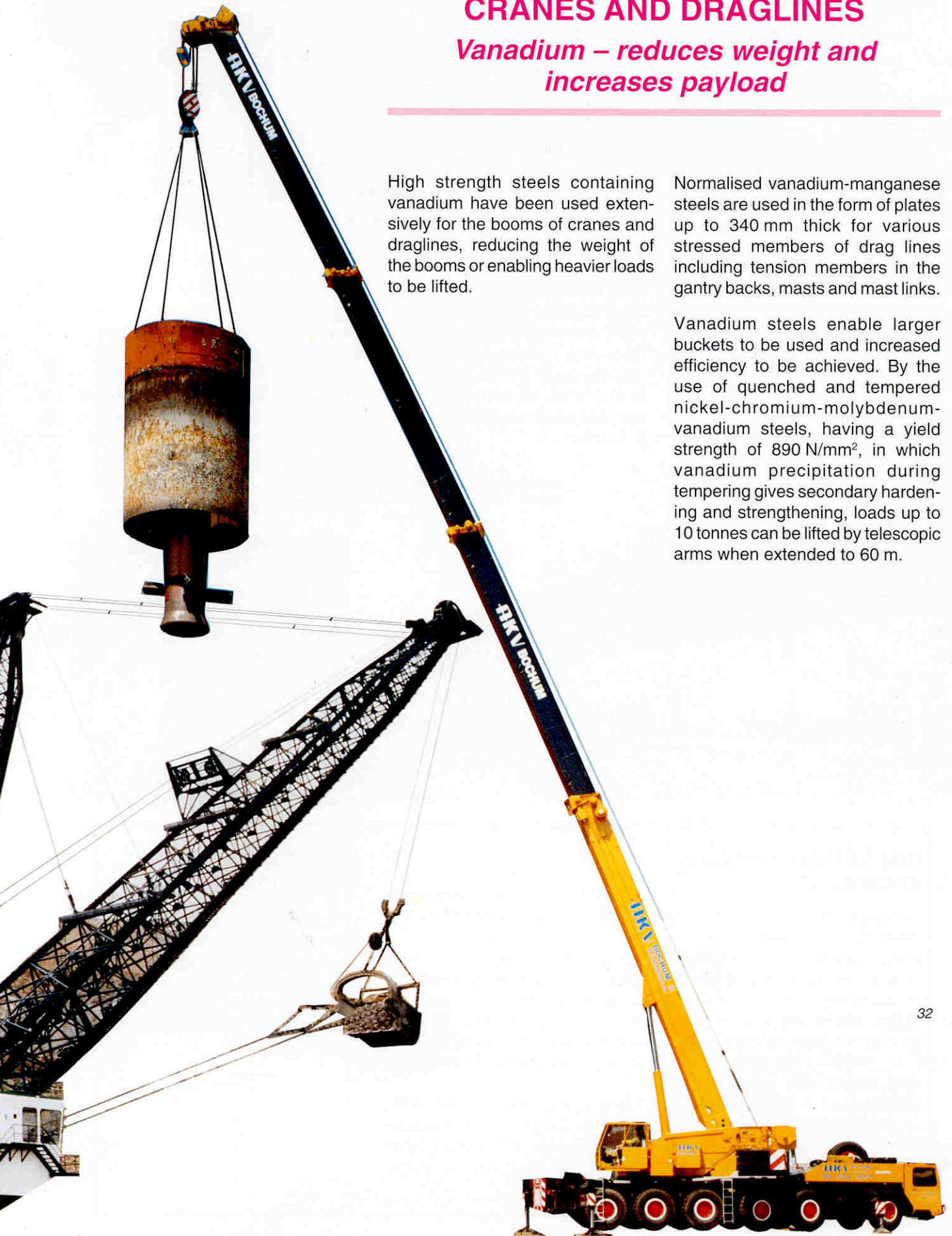
CRANES AND DRAGLINES

Vanadium – reduces weight and increases payload

High strength steels containing vanadium have been used extensively for the booms of cranes and draglines, reducing the weight of the booms or enabling heavier loads to be lifted.

Normalised vanadium-manganese steels are used in the form of plates up to 340 mm thick for various stressed members of drag lines including tension members in the gantry backs, masts and mast links.

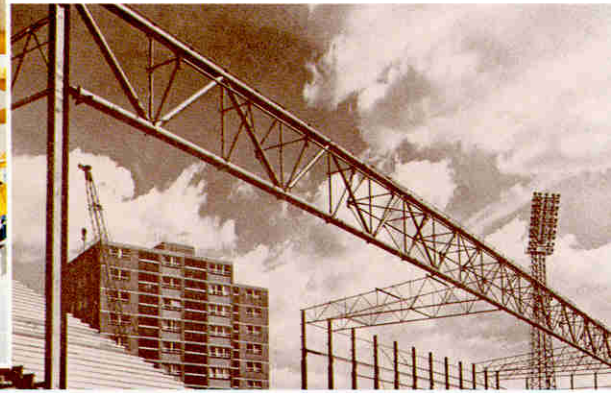
Vanadium steels enable larger buckets to be used and increased efficiency to be achieved. By the use of quenched and tempered nickel-chromium-molybdenum-vanadium steels, having a yield strength of 890 N/mm², in which vanadium precipitation during tempering gives secondary hardening and strengthening, loads up to 10 tonnes can be lifted by telescopic arms when extended to 60 m.





Sports stadium, Sheffield, England

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Football stadium, Bristol, England under construction

Vanadium steels in tubular structures

As long ago as the 1970s vanadium was used to provide extra high strength in steels used for welded tubular structures. Such tubes were used in the British Airways hangars at Heathrow airport and in the spectator stand at Bristol City Football ground.

More recently vanadium steels have been used to provide strength in thick walled structural seamless tubes such as those used in some of the columns in the terminal building at Stanstead Airport and in certain complex joints in the sports stadium in Sheffield.

In all these applications the use of high strength tubular structures enables large unsupported spans to be built so that in sports stadia spectators can have views unimpeded by pillars and aircraft hangars can be constructed so that large aircraft can have free access.

Vanadium steels have also been used in tubes in chemical plant and oil refineries.



Terminal building, Stanstead Airport, England

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Hot formed pressure vessels

In many parts of chemical plant made from steel plates, such as pressure vessels, the plates have to be formed to shape after heating to make them soft. Vanadium steels which depend for their strength on grain refinement and precipitation formed during normalising are very suitable because the thermal cycles during fabrication involve temperatures similar to those used in normalising. As a result of this the structure and properties of the

plates remain largely unchanged despite the fabrication conditions.

Vanadium steels are also preferred for bends and manifolds in high strength pipelines because the heating for the forming operations has little effect on their strength and other properties.

Vanadium steels are frequently used for forged valves because they can be normalised after forging to give high strength without distortion.

Vanadium steels in Industrial buildings

In North America "as rolled" vanadium steel sections are used extensively in the frames and roofs of industrial buildings. In these steels vanadium carbonitrides precipitated in ferrite provide the strength.

VANADIUM provides the varied combinations of properties in cast iron, heavy steel forgings and plate for

INDUSTRIAL PLANT AND TUBULAR STRUCTURES

Vanadium – for reliability and durability in steel and cast iron

Vanadium in rolling mill rolls

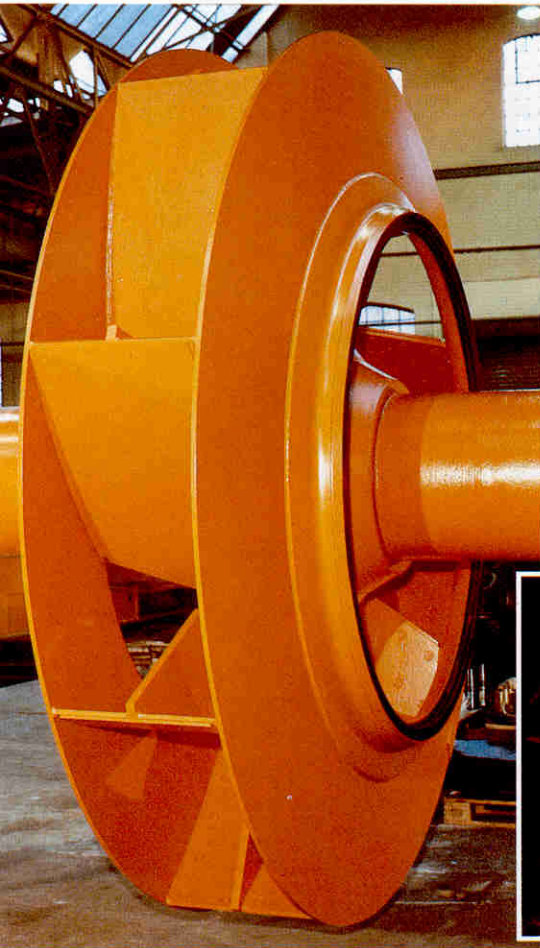
Vanadium is an essential alloying element in a number of steels and cast irons used for rolls in steel mills. The vanadium, however, has several different functions depending on the product being rolled.

Cast iron finishing rolls for steel plate mills

Up to 1% vanadium is added to cast iron rolls used for the hot rolling of steel plate. The function of the vanadium is to increase the depth of chill and hardness on the surface of the rolls so that when polished the high quality surface of the roll imparts an equally high quality surface to the steel plate.

The hard surface containing vanadium carbides also ensures that cracks do not form under thermal cycles resulting from the rolling of the hot steel.

Vanadium also refines the graphite of the core thus increasing the strength and toughness of the iron enabling it to resist impact loading during rolling operations.



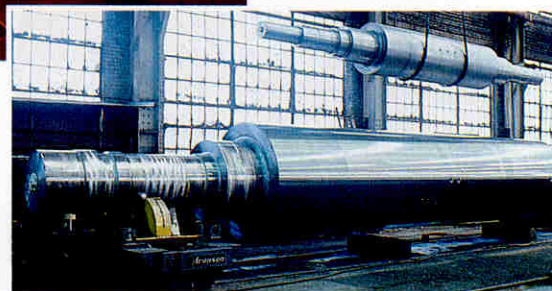
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Heat treated steels for industrial compressor rotors

Fully heat treated nickel-chromium-molybdenum-vanadium steels having a yield strength of 890 N/mm² and a high resistance to wear are used for large rotors operating at high speeds to circulate large volumes of air in sinter and pelletising plant in the steel industry.

Forged steel back up rolls in four high mills

Small amounts of vanadium (of the order of 0.1%) are added to forged steel back up rolls of four high mills to refine the grain size and hence increase the toughness of the rolls. This enables the rolls to resist impact loading during rolling operations.



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Similar rolls with up to 0.25% vanadium have been used in the work rolls of hot strip mills.

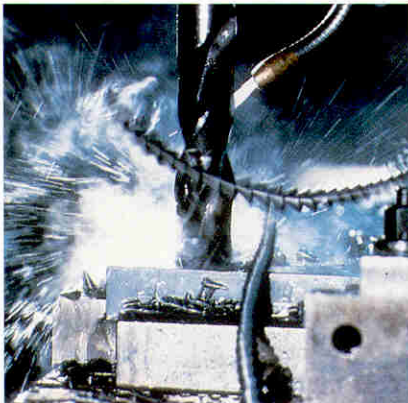
Vanadium in high carbon steels forms hard primary carbides during casting sometimes in combination with other alloying elements present in the steel. These carbides are stable at high temperatures and mostly remain in primary form throughout subsequent forging and heat treatment operations. They are the basis of the wear resistance and cutting performance of cold pressing dies and tools. The stability of these carbides at high temperatures makes the steels

containing them suitable for high-speed machining operations and gives wear resistance to hot forging and pressing dies.

In addition to the primary carbides, some vanadium remains in solution and contributes to the hardenability, strength and toughness of the tools and dies. During heat treatment some additional hardening occurs to give increased wear resistance as a result of the precipitation of very

fine particles of secondary vanadium carbides.

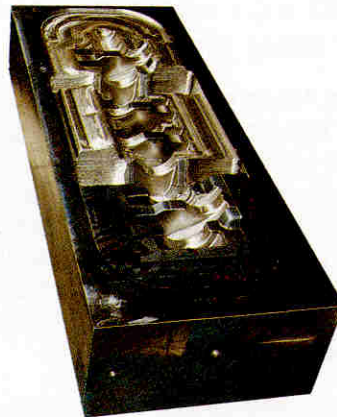
By varying the composition and heat treatment a wide variety of property combinations can be obtained. This makes it possible for steels to have the very different properties required in high-speed tools and dies used in the automobile and heavy engineering industries and for domestic hand tools such as spanners and screwdrivers.



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High-speed steel

All tools used for the machining of steel at high speed, as in the production of automobile components, require a cutting edge which is capable of being stable at the high temperature reached at the tool tip which can be in excess of 600 °C. Particles of vanadium carbide formed during the casting of the steel and which remain out of solution throughout the heat treatment operations satisfy this requirement. The original high-speed steel developed at the beginning of the century contained 1% vanadium. Improved and lower cost versions were developed in the middle of the century and they are now the standard steels and contain 2% vanadium.

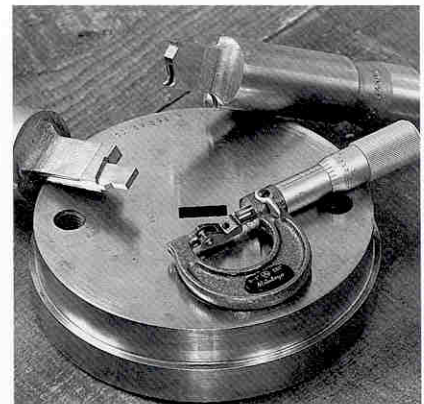


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Hot forging dies

Dies for hot forging, stamping and pressing operations have to withstand high surface temperatures (up to 1 500 °C) and thermal shock. In addition they have to resist high pressures and, in the case of stamping dies, impact loading. In order to meet these conditions of service microstructures giving a tough steel with a hard surface are required and they are provided by relatively high tungsten-vanadium steels. The tungsten and vanadium provide the hardenability necessary to ensure a tough core and a surface containing carbides which provide the resistance to wear.

Many dies can be resurfaced after use and are therefore recyclable.



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Cold pressing dies and tools

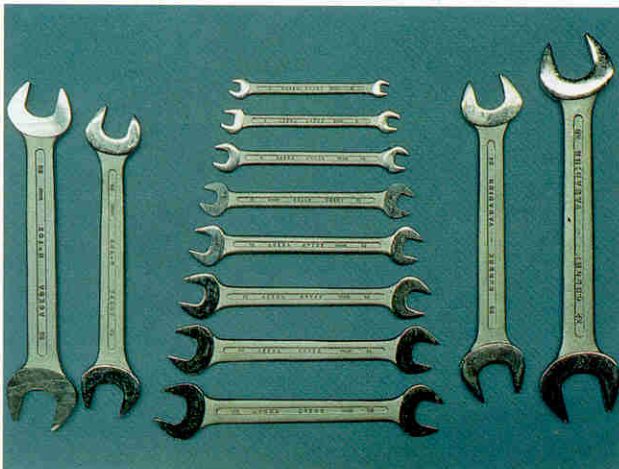
Cold pressing dies and tools handling hard materials must have high abrasion resisting surfaces. These can be produced by high vanadium contents. Normal casting tends to give coarse particles of carbides which can lead to cracking during forging except for small tools. Recent developments have taken place in powder metallurgy techniques which have resulted in refined microstructures so that large tools and dies can now be made. Tools and dies containing as much as 10% vanadium can now be produced for punches and dies by these powder metallurgy methods. Knives, shear blades, extrusion dies, pelletiser blades and screw conveyors, handling metals, plastics and other abrasive materials also benefit from powder metallurgy alloying. Similar tools operating in wet conditions are made from more corrosion resistant steels containing 4% vanadium.

VANADIUM creates the hardness for cutting edges and wear resistance required in

TOOLS AND DIES

Vanadium steel tools for the professional, the craftsman, the handyman and the machine shop

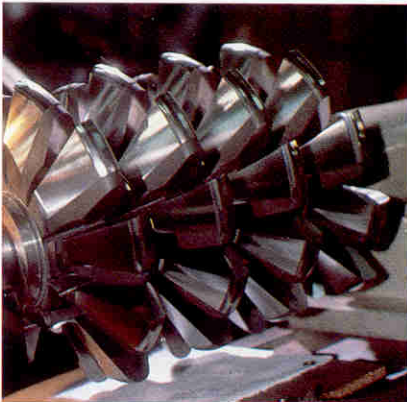
Vanadium tool and die steels are melted in induction furnaces and scrap steel is recycled without significant loss of vanadium



Chrome-vanadium steels for spanners and domestic tools

In spanners, screwdrivers and other domestic and engineering tools vanadium and chromium are added to increase the surface hardness and resistance to distortion under load. Vanadium is added with chromium to provide strong, wear resistant tools.

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General tool steels

Vanadium is added to many grades of carbon steel used for lathe tools and milling cutters, blacksmith's tools, stamping dies, rock drills, chisels, wood cutting tools and razor blades. The precipitation of fine particles of vanadium carbide during heat treatment of the tools increases their hardness and improves their cutting efficiency giving them longer life. Vanadium, through its effect on hardenability increases the depth of hardness in heat treated tools which increases their resistance to crushing, their toughness and hence their resistance to fracture under impact loading.



Tap dies, reamers, punches, planes, chisels and shear blades

In tools which have a cutting function the cutting edge is provided by hard carbides. The iron carbide of carbon steels is supplemented by the harder carbides of vanadium and tungsten in tools which undertake severe cutting operations. Thus planes, chisels, reamers and shears, especially those used for cutting hard materials or heavy sections of softer materials, are made from vanadium-tungsten steels.



Cutlery steels

Vanadium is added to chromium cutlery steels to increase the hardness of the steel and to give a longer-lasting, better cutting edge.

VANADIUM

PROTECTS HEALTH – PROVIDES MEDICINES

ASSISTS SURGERY – CONTROLS POLLUTION

Vanadium – the “green” metal

Vanadium pentoxide protects our eyes, our bodies, our food and our medicines from the sun’s harmful ultraviolet rays.

Vanadium pentoxide in glass for telescopes, cameras and other optical instruments is used to absorb ultraviolet light to protect the operators and to prevent fogging of photographs.

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The lenses are mounted in a vanadium-titanium alloy having a similar coefficient of thermal expansion to the glass of the lenses.



Vanadium pentoxide absorbs ultraviolet light and when added to the glass or plastic used for spectacles it protects the eyes from the harmful effects of these rays.



Glass containing vanadium pentoxide is used in buildings to protect occupants from ultraviolet light in the sun’s rays.

When vanadium pentoxide is added to glass or plastic used for bottles and jars, the absorption of the ultraviolet rays protects medicine and food from premature oxidation, photolysis and photo-degradation.



Vanadium catalysts are used in the production of Vitamin A.

Vanadium gives strength to titanium alloys used in replacement hip joints.



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Throughout the 20th century vanadium has played an important part in industry to protect the environment, reduce pollution and produce materials of benefit to health.

Vanadium catalysts remove harmful constituents from effluents and natural gas

1920s In the 1920s Philip Stacey Lewis, a young PhD from Liverpool University working at a zinc smelting plant in South West England, found that vanadium pentoxide could be used to catalyse the conversion of SO_2 to SO_3 which could be made into sulphuric acid and was unaffected by arsenic compounds which poison platinum catalysts. At that time the sulphur dioxide from the zinc plant was polluting the surrounding countryside but by the use of vanadium pentoxide to catalyse this reaction this pollution could be prevented. The discovery, which had been made independently some years earlier in Germany, enabled vanadium pentoxide to replace platinum in the UK production of sulphuric acid. Vanadium therefore became essential in the efficient production of wheat and other crops which use fertilisers made with sulphuric acid.

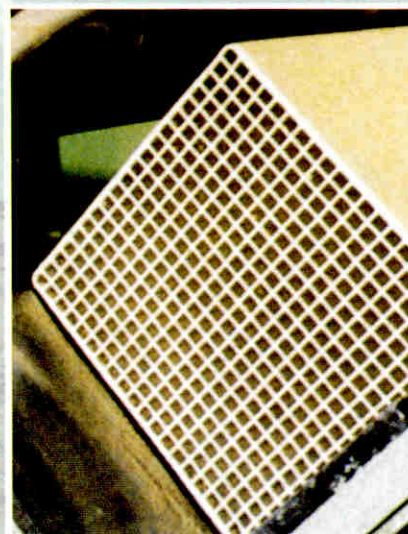


1990s Vanadium continues to have an important role in environmental protection due to the ability of its compounds to catalyse redox and other chemical reactions through which it contributes to a number of processes which remove toxic and corrosive compounds from effluents.

Vanadium removes hydrogen sulphide from natural gas

Poisonous, objectionable and corrosive hydrogen sulphide, a constituent of natural gas from many oil wells and present in the effluents from sewage plant is removed by the catalytic action of a vanadium salt. The natural gas is

washed in a scrubber through which an alkaline solution containing a pentavalent vanadium salt is circulated. The sulphur is converted to a sodium sulphide and then to elemental sulphur which is sold as a by-product. The vanadium which is reduced during the process is oxidised back to the initial state and recirculated.



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If natural gas containing sulphur is not treated with vanadium the gas can cause severe corrosion of pipelines or require expensive special alloy steels to prevent corrosion.

Vanadium removes nitrogen oxides from fossil fuel power plant effluents

In processes for the removal of poisonous nitrogen oxides from the effluents of fossil fuel electric power generating plant, ammonia is fed into the gases which are passed

over trays of honeycombs of catalysts containing vanadium chemicals. These convert the nitrogen oxides to harmless nitrogen and water vapour which then enter the atmosphere.

Vanadium enables synthetic rubber to be produced from ethylene and propylene

Vanadium oxytrichloride is used to synthesise caoutchouc in the production of artificial rubber. The rubber is used extensively for coating chemical reaction tanks and roofing as well as for domestic and sporting applications such as golf balls.



VANADIUM

SUSTAINS AND IMPROVES THE QUALITY OF LIFE

Vanadium – the aesthetic metal

Vanadium salts provide colours in domestic and decorative ceramics

Vanadium salts together with other chemicals are well known for the brilliant orange and blue colours which they can produce in ceramics and enamels. They continue to be used to produce these colours in all kinds of products.



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Vanadium enables nylon 6,6 to be produced via adipic acid and protects steel in the processing vessels from corrosion.

Adipic acid used in the production of nylon 6,6 is made with hydrogen obtained from methane in a process employing alkali vanadates.

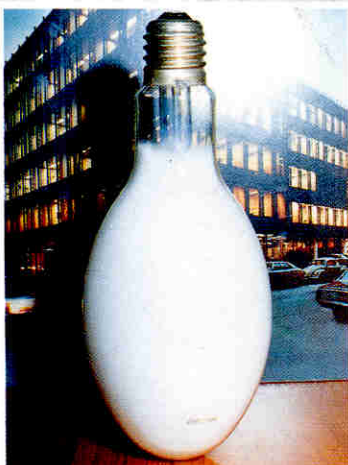
Carbonic acid formed from carbon dioxide produced during the reaction can give rise to severe corrosion of steel in the plant but this is inhibited by the vanadium compounds.

Vanadium salts enable lasting dyes to be produced for textiles and leather

Vanadium oxide reacts with organic compounds to produce dyes for textiles and leather which resist fading in strong sunlight. The famous black anthracene dyes depend on the vanadium catalytic conversion.



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Vanadium improves the colour of light from mercury lamps

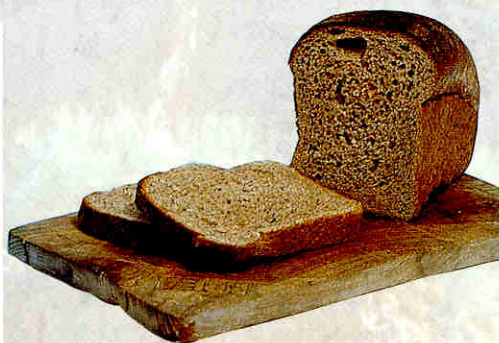
A combination of vanadium and yttrium oxides has a surface which reacts with short wave light from high density mercury to emit wavelengths at the red end of the spectrum. By applying a coating of yttrium-vanadium oxides to the surface of high intensity mercury lamps, the emission of the red light together with the characteristically green light emitted from high pressure mercury lamps results in a high intensity white light.

Through its function as a catalyst in the production of sulphuric acid, vanadium enables millions of tonnes of fertilisers to be produced every year

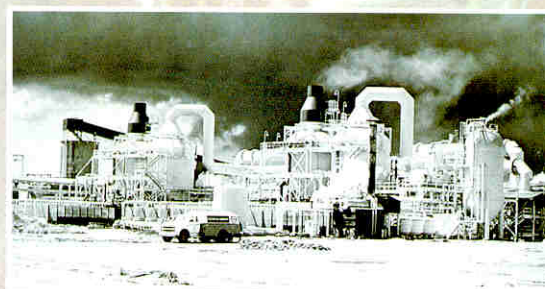


Vanadium makes possible the storage of energy for electric power generation.

The growing concern over pollution is promoting the use of hydrogen storage batteries for many current applications, including electric cars. Hydrogen storage batteries which use vanadium alloys to store the hydrogen have a higher unit capacity and give less pollution than conventional batteries.



Vanadium pentoxide is used as a catalyst for the oxidation of sulphur dioxide to trioxide in the manufacture of sulphuric acid which is the basis for the production of fertilisers throughout the world. Without these fertilisers the production of cereals and other foods on the scale required to maintain basic food production for the modern world would not be possible.



Vanadium improves the colour quality of television and computer screens

Vanadium phosphor emits a red light when bombarded with electrons and is used in the coatings of television and computer screens to improve the quality of red light.

Vanadium enables plastics to be produced from oil and coal

The redox-catalytic activity of vanadium oxide enables the controlled catalytic oxidations of naphthalene and ortho-oxylene to phthalic-anhydride and of butane and benzene to maleic-anhydride to take place. Both compounds are essential monomers in the production of polyesters and plastics.

Vanadium brings brightness to plastics

Vanadium in certain plastics produces brilliant and stable colours.



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Vanadium can also be used as an anode in batteries and enables them to operate at temperatures down to -40 °C.

VANADIUM – ITS INCREASING ROLE IN

THE TWENTY FIRST CENTURY

Vanadium – the metal of the future

Vanadium steels for high-energy, high-speed autogenous welding

New autogenous welding processes are being developed which make use of the high energy available in lasers and electron beams to increase the speed and reduce the cost of welding. These processes also avoid the use of filler materials as commonly required in arc welding.

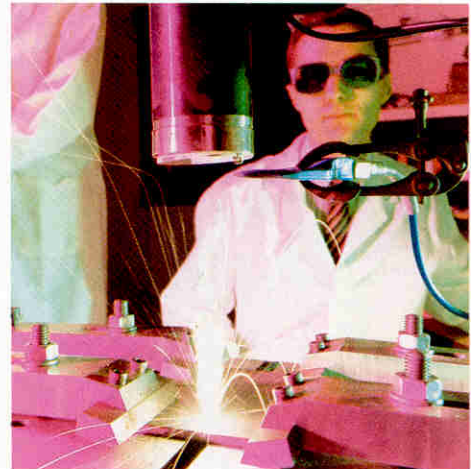
Arc welds often contain significant quantities of fine oxides introduced via the welding consumables that promote fine grained microstructures associated with toughness in the welds. The beam welding processes however have fused zones which contain very few oxide particles and as a result, coarse microstructures are often developed in the fused zone tending to give brittleness.

Unlike most other alloys vanadium tends to stabilise ferrite and produces a special microstructure

known as intragranular ferrite which increases the toughness of welds at low temperatures. Vanadium steels therefore have a possible advantage over other steels for use in structures welded by these processes.

The laser welding process has many applications and is being considered for ship building.

Laser welding can also be used on board ship and the process has a potential for use on barges laying oil and gas pipes in deep water where the pipes have to be welded using a single pass with the pipes in the vertical position. Vanadium steels therefore with their characteristic of giving a fine grained, tough weld have a potential for use in offshore pipelines to be laid in deep water for which there will be an increasing demand.



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The electron beam process has an even higher power source and can be used for welding thicker plates (50 - 100 mm). It is being developed for the seam and the girth welding of thick walled oil and gas pipes and for offshore structures. The beneficial microstructures of welds offered by vanadium steels make them candidates for all these applications.

Vanadium steels in electric generating plant of the future

In the quest for increased efficiency and lower cost of electric power generation, combined cycle plant is now being developed. In this plant the primary unit is a gas turbine which will be driven by natural gas. The exhaust gases from this turbine will be used to generate steam which will drive a steam turbine generator.

Developments are also taking place in the use of steam above the critical temperature which would mean that steam temperatures of the order of 650 °C will be involved, giving an



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increase of generating efficiency from the present maximum of 43% to above 45%. Steels in such power plant are required to have ex-

ceptional creep properties but chromium steels containing vanadium, niobium and tungsten appear to be effective.

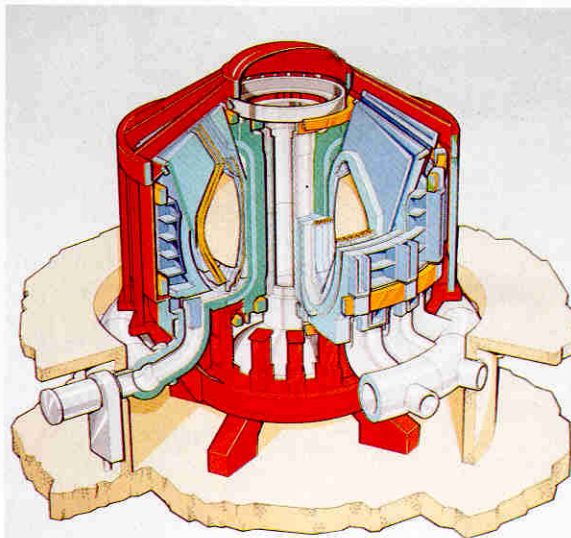
New materials to meet the engineers' demands of the future

Fusion reactors

There is increasing concern about the environmental effects (global climatic changes and the impact of acidic emissions) of burning fossil fuels. There is also public unease over the safety of nuclear fission. These considerations will make it difficult for these energy sources to meet the large increases in demand that will inevitably result from population increases in the less developed countries over the next 50 years. Fusion energy represents an alternative that has been shown to have major potential safety and environmental advantages over all other means of base-load electricity generation, at broadly comparable cost.

Several decades of research and development will be needed before commercial fusion energy can be realised but the property requirements of the materials to be used in the most critical parts of a reactor are already fairly well defined. Furthermore, it is

clear that the physical and nuclear properties of vanadium make vanadium-based alloys, probably containing chromium and titanium, strong candidates for the structural material of the core.



Conceptual design of fusion reactor

The properties of vanadium that make its alloys attractive to the nuclear engineer include its high melting point of 1887°C and the fact that 80% vanadium alloys containing chromium and titanium

additions possess high creep resistance at temperatures in the region 698-797°C. They are therefore likely to have the required strength for the core structure and would maintain this strength at relatively high operating temperatures. Vanadium also has a high resistance to attack by lithium and lithium-lead alloys, which could be used as coolants.

Vanadium, together with chromium and titanium, also exhibits a low rate of nuclear transmutation. This is associated with low production rates of hydrogen and helium, thus minimising the risk of swelling and embrittlement of the alloys. Moreover, radioactive transmutation products of vanadium are few in number and decay relatively quickly compared with most other metals. This property would possibly have advantages both in operational safety and in management of expired materials and offers the potential for recycling.

Ultra-light, ultra-strong, complex alloys for aircraft



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Metal matrix composites for aero-engine components

Metal matrix composites of silicon carbide continuous reinforced titanium-vanadium-aluminium alloys offer the possibility of lower density materials which will operate at considerably higher temperatures than those at present used for compressors and other aero-engine parts.

New low density, aluminum-iron-silicon-vanadium alloys with improved corrosion resistance and higher strength at temperatures up to 315 °C are being developed for the compressors of aero-engine gas turbines. These will enable higher intake temperatures to be used which will reduce fuel consumption. The alloys also have a potential for aircraft wheels particularly for military aircraft where severe braking produces high temperatures.

Vanadium high carbon grey cast irons for brake discs and drums

Heavy trucks operating at high speeds put a strain on the discs and drums in braking systems and there is a demand for improved materials. Vanadium, when added to grey cast iron, refines the graphite and

increases the strength without reducing the thermal conductivity or thermal fatigue resistance. These irons are therefore candidate materials for brake drums and discs of the future.

VANADIUM – SOME BASIC FACTS

Vanadium – the interesting metal

Environmental properties

Biological

Essential to life for some species

Levels in humans

Muscle	0.02 ppm
Bone	0.0035 ppm
Blood	<0.0002 mg dm ⁻³
Daily intake	0.04 mg

Geological

Earth's crust 160 ppm

Sea water

Atlantic surface:	1.1 x 10 ⁻³ ppm
Atlantic deep:	n.a.
Pacific surface:	1.6 x 10 ⁻³ ppm
Pacific deep:	1.8 x 10 ⁻³ ppm

Atomic Characteristics

Unit cell: b.c.c. 1m3m a = 0.302 nm
Co-ordination: 8 Atomic number: 23
Mean atomic weight: 50.9415
Isotopes: 47, 48, 49, 50*, 51*, 52.
*Stable
Electron shell configuration: 1s², 2s², 2p⁶, 3s², 3p⁶,
4s², 3d³

Physical Properties

Melting point: 1 887 °C
Boiling point: 3 377 °C
Δ H (fusion): 17.6 kJ mol⁻¹
Δ H (vap): 458.6 kJ mol⁻¹
Density: 6 110 kg m⁻³ (19 °C)
5 550 kg m⁻³ (liquid @ m.p.)
Thermal conductivity: 30.7 W m⁻¹ K⁻¹ (27 °C)
Coefficients of linear thermal expansion:
8.3 x 10⁻⁶ K⁻¹ (23 - 100 °C)
9.6 x 10⁻⁶ K⁻¹ (23 - 500 °C)
10.4 x 10⁻⁶ K⁻¹ (23 - 900 °C)
10.9 x 10⁻⁶ K⁻¹ (23 - 1 100 °C)
Electrical resistivity: 19.1 M μΩ cm (20 °C)
Mass magnetic susceptibility: 6.28 x 10⁻⁸ m³ kg⁻¹
Molar volume: 8.34 cm³
Modulus of elasticity: 12.4 x 10⁴ N mm⁻²

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