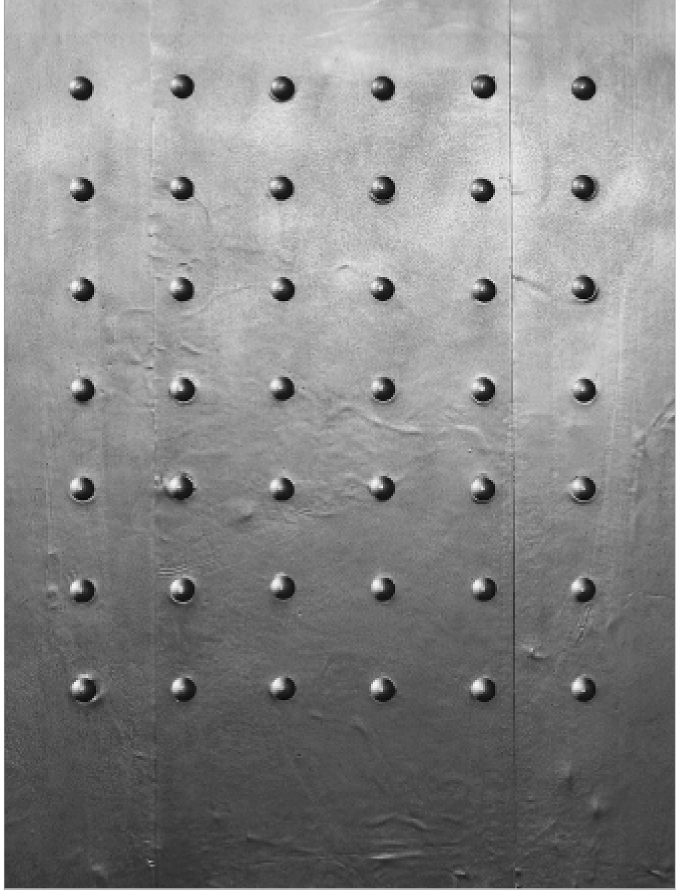
TITANIUM

Facts



WHAT DO YOU THINK OF WHEN YOU THINK OF TITANIUM?

Do you think of titanium as an exotic, “space age” metal used in aircraft and jet engines?

An expensive, precious metal found on museum walls in Spain and a credit card in the US?

A novelty found in golf clubs and mountain bikes?

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Well, you’re half right.

Titanium isn’t exotic, expensive, new or a novelty.

Titanium is used to build aircraft and jet engines; as an architectural material (and an attractive bankcard image); and in a variety of sporting gear.

In fact, titanium is more commonplace than you probably think.

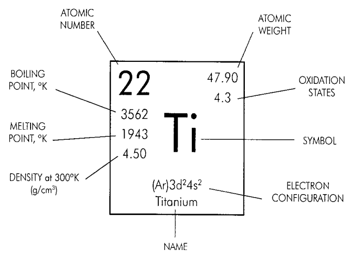
Titanium lets us fly higher and faster, get more enjoyment from our recreation, rely on our electrical power without worry, produce the chemicals and oil and gas we need at a lower cost, make the roofs of buildings last longer, and even save lives through medicine.

Titanium improves goods and services and our quality of life in countless ways everyday.

And you probably don’t even know its atomic number.

Titanic, the most famous ship since Noah’s Arc, lay undisturbed under 13,000 feet of water for more than 70 years, until a submersible three-person sphere made of titanium, the Nautile *(built by RMS Titanic, Inc.)* allowed scientists to investigate the wreckage in water that exerts 6000 pounds of pressure per square inch.

The Basics - Part I — Titanium is a common element.



Titanium is an element — number 22 on the Periodic Table, falling somewhat near iron, nickel and copper.

It is the ninth most abundant element in the earth's crust, and the fourth most abundant metallic element.

In nature, titanium is found in the forms of rutile (titanium dioxide, TiO_2) and ilmenite (titanium iron oxide, $FeTiO_3$). These two mineral forms are the most common and commercially exploitable.

Other forms of titanium occur as leucoxene, a natural alteration of ilmenite, anatase, a naturally occurring mineral of titanium dioxide, and perovskite, ($CaTiO_3$).

Ilmenite is common in igneous rocks, with major deposits found in South Africa, Norway, Australia, Canada, Finland and the US.

Major deposits of rutile and ilmenite are found in beach sand, near continental coastlines where erosion and wave action have elevated concentrations of the minerals.

The majority of the naturally mined rutile today comes from Australian beaches, where it appears as common black sand.

The main economic reserves of rutile are found in South Africa, India, Sri Lanka, Australia and Sierra Leone.

The world reserves of ilmenite total about 70 years of 1996's ilmenite production; reserves of rutile total about 50 years of 1996's rutile production.

Today, while ilmenite provides 90% of the total world titanium mineral supply, it is almost totally used in metal production to make synthetic rutile, and titanium slag. Together, the synthetic and natural rutile are the principal raw material for titanium production.

However, of all of the mined and synthetic titanium minerals, only about 5% is used to make titanium metal. The other 95% is used to manufacture pure titanium dioxide, TiO_2.

Titanium dioxide, TiO_2, is a pigment that imparts whiteness, brightness and opacity to paints, paper and ink, plastics and even food products and cosmetics.

The Basics Part II: Titanium Properties Are Unique

While titanium as a mineral is fairly common, titanium's metallurgical properties make it unique. Or, more accurately, its combination of properties — it's the synergy of characteristics that drives the use of titanium in hundreds of applications.

Titanium is both strong and lightweight — as strong as steel, but weighing only 56% as much as steel. That gives it the highest strength-to-weight ratio of any of today's structural metals. To produce structures of the same strength, far less titanium is required than other metals. Or, put another way, if plates of the same weight are made from titanium, copper and stainless steel, the titanium plate will be twice as large as the copper one and 75% larger than the stainless steel one.

Titanium naturally resists corrosion from acids, alkalis, and natural, salt and polluted waters. In fact, titanium's resistance to seawater is equivalent to that of platinum. This is because titanium is a reactive metal, spontaneously forming a hard, protective oxide film when it comes in contact with any oxygen — as in air or water. If the film is scratched or damaged, as long as oxygen is present it will heal itself.

The protective film also makes titanium very resistant to erosion. In high velocity process streams and in rapidly flowing seawater, it can be at least twenty times more erosion resistant than copper-nickel alloys.

Titanium's naturally occurring oxide film also gives the metal its unique, softly shimmering beauty. When the thickness of the film is increased (through anodic oxidation) it changes the appearance of the metal over a spectrum of colors.

Titanium has a low modulus of elasticity — about half that of steel. This gives it excellent flexibility and allows it to spring back to its original shape when bent.

It is the most biocompatible of all metals. It is non-toxic, it resists attack from bodily fluids, it's strong and light, and it's flexible, to move with the body.

Titanium is an environmentally friendly metal. It comes from an abundant natural resource which is mined with minimal impact, no harmful by-products are generated in its production and 95% of its scrap is recycled.

During the Barcelona Summer Olympics, the Olympic flame burned in a cauldron made of titanium. The cauldron's designer chose titanium for its image of technological advancements and its unusual beauty.

Add it up: Titanium Pays Off

Titanium's remarkable combination of metallurgical and physical characteristics use in a given application can generate a synergy of benefits. It is most successfully employed when the initial design exploits its unique attributes, rather than when it is merely substituted for another metal.

In some applications, like jet engines and medical implants, titanium allows the item to perform to its maximum potential.

In other cases, titanium improves an item's performance so dramatically, it is worth a cost that's a little more than a competing material. This is the case in golf clubs, for example, where people will pay a little more for a titanium club that enhances their playing experience.

In chemical processing and marine environments, for example, titanium's long (and often virtually unlimited) lifespan makes it the choice over other metals because, while its upfront cost may be higher, its total life cycle cost is lower.

Finally, in some situations, the use of titanium can impact the entire design, making it more efficient and cost-effective. This is the case in offshore oil and gas platforms, where titanium riser pipe below the surface saves three times its weight on the overall structure and anchoring system.

Titanium: Elegant Application Solutions

The Aerospace Industry Wouldn't Fly Without It

Because it is light weight, strong, corrosion resistant, and has excellent elevated temperature characteristics, titanium's largest use is in jet engines, where it is employed for fan blades, compressors, discs and critical rotating components. In a typical gas turbine engine, titanium makes up some 20 - 30% of the weight. In total, it's estimated that engines account for about 42% of US titanium demand and 37% of titanium demand in Europe.

Titanium is also used in airframes, in parts ranging from massive forged wing structures to critical small fasteners, springs and hydraulic tubing.

The Boeing 777 requires nearly 50 tons of titanium per aircraft including the engines, accounting for nearly 9% of its empty operating weight.

Since the 1940's, titanium has been an aircraft metal. It was first used in flight on the Douglas Aircraft X-3 Stilleto after the US Department of Defense recognized the metal as a solution to high-speed design challenges.

In military aircraft, the percentage of titanium has progressively increased with technological advances. In the 1960's, the Phantom F-4 was about 9% titanium by weight; today's F-22 is over 39% titanium. The military's SR-71 Blackbird, though no longer in production, still holds all speed and altitude records and was made 90% from titanium.

In spaceflight, titanium was used on the early Mercury missions, the Apollo missions and is now used in the Space Shuttle and its solid rocket booster cases. An important future use will be in the International Space Station.

One of the most unusual uses of titanium is in clothing, although only two known examples exist. The first was in a brassierre manufactured by Wacoal America, which used nickel-titanium alloy underwires that returned to their original, comfortable shape if bent, the second was in sport jacket made of small titanium plates that was presented to architect Frank O. Gehry in recognition of his use of titanium to clad the exterior of the Guggenheim Museum in Bilbao, Spain.

Industrial Applications Are As Varied As The Industries Themselves

Titanium's first use in industry was for condenser tubing in sea-water-cooled electrical power generating plants, due to its corrosion immunity. Since 1971, over 300 million feet of titanium tubing has been installed in power plants without any incidence of corrosion-or erosion-related failure.

In chemical processing, titanium is used to make heat exchangers, vessels, pipe and tubing that resist aggressive oxidizing acidic and chloride solutions, temperatures and pressures. In the late 1950's, it was discovered that small alloying additions of palladium improved titanium's resistance to non-oxidizing acids by as much as 1500 times.

For general marine use, titanium is either resistant or immune to corrosion in natural and polluted seawater, where copper and stainless steels are susceptible. It's for this reason, and its strength, that titanium is finding utility for everything from screw propellers to shipboard sprinkling systems. Titanium performs so well that some producers warranty it for up to 100 years in certain applications.

In Saudi Arabia, nearly 46% of the drinking water comes from desalination, and thin-wall titanium tubing is used in the multi-stage evaporation plants in the rejection, heat recovery, and heat input stages, as well as the more critical rejection stages.

Consumer and Commercial Uses Make Titanium an Everyday Material

Many people recognize that titanium golf club woods soared in popularity in 1996, when they consumed nearly 20% of total US titanium production. Just five years prior, they were virtually non-existent.

Club heads cast from titanium are lighter and therefore can be larger than those made of other materials, affording the club a bigger "sweet spot" which increases distance and accuracy. In Japan, it's estimated that better than 10% of amateur golfers use titanium clubs.

High performance bicycles, skis, tennis rackets and even lacrosse sticks made from titanium are becoming more common. Softball bats made from titanium have been tried, but there is a danger that the speed they impart to hit the ball is so extreme that players will not be able field the hit before it injures them.

Other consumer products are diverse and imaginative: titanium eyeglass frames are lightweight, comfortable and attractive, and if they're bent, they snap back to their original shape; titanium watches have been mass produced since 1987; camera cases of titanium are strong, dent-resistant and light; non-stick titanium coatings on cooking utensils are corrosion- and scratch-resistant.

In construction, titanium's natural resistance to environmental attack, as well as its strength, modulus and beauty are creating a market for the metal. It was first used for roofs in Japan, where it must withstand salt air, and now construction use accounts for 9% - 10% of the Japanese titanium market.

The dramatic, flowing Guggenheim Museum in Bilbao, Spain, designed by famed architect Frank O. Gehry, is clad in 343,000 square feet of interlocking titanium flat seam panels, giving it a softly shimmering appearance.

Titanium has been used in medical applications since the 1950's. It is the most biocompatible of all metals and in prosthetic and replacement devices, it actually allows human bone growth to adhere to the implants, so they last longer.

Pacemaker cases are made from titanium because it resists attack from bodily fluids, is light weight and flexible and is non-magnetic. Artificial heart valves are also made of titanium.

The titanium industry is devoting significant effort to developing automotive applications, as even a pound of titanium on every new car would make this a larger market than aerospace.

You probably know a 25th Anniversary is a Silver Anniversary, and the 50th is Gold, but do you know which Anniversary is titanium? It's the 45th.

Titanium valve train components have demonstrated they can improve a car's fuel efficiency by up to 4%. Titanium suspension springs could offer weight savings up to 70% compared to steel, as well as complete corrosion resistance. Titanium engine springs could allow faster engine speeds and better fuel economy.

The Honda NSX sports car uses connecting rods made from titanium that reduce the weight of the car enough that a turbocharger isn't needed to achieve maximum performance.

Concept cars built using titanium have been tested since 1956, when GM built an all-Ti Firebird.

The automotive racing industry uses titanium valves, valve springs, suspension springs, connecting rods and rocker arms.

The Thrust SSC car, which broke the world land speed record a few years ago uses titanium for the rear fuselage skin section and fin.

In fiction and movies, titanium has played a variety of supporting roles. It is found in Russian Alfa submarines in Tom Clancy's *Hunt for Red October*, as massive wedding band in *The Abyss*, written by James Cameron, as a prosthetic material for Lieutenant Day's new legs in the movie *Forrest Gump*, and it's miscast in the metaphor "the atmosphere seems heavy enough to be made of titanium" in *The Prince of Tides* by Pat Conroy.

Titanium's History

Titanium was discovered in 1790 when Reverend William Gregor, an amateur geologist, identified the element in black sand on the Cornish beaches in England. He suggested the new metallic substance be called Manacannite, after a nearby parish.

Five years later, an eminent German chemist, Martin Heinrich Klaproth, recognized a dioxide of the same metal in rutile ore (TiO_2) and called iit "Titanium" after the Titans, mythological Greek gods of enormous strength. However, his attempts to isolate the metal failed.

It wasn't until 1910 that an American chemist, M. A. Hunter, finally succeeded in extracting titanium metal from the ore and this marked the birth of the titanium industry.

Hunter's process involved mixing TiO_2 with coke and chlorine and applying heat, to yield titanium tetrachloride ($TiCl_4$), which he then reduced with sodium. The titanium was mainly used as an alloying element in steel.

At the most celebrated temple of ancient Greece, the Parthenon, high atop the Acropolis, the marble pillars have been restored using more than 1000 reinforcing rods and clamps made of titanium, because it won't rust and expand, and thus crack the marble.

Titanium dioxide was also a by-product of the Hunter Process and it was recognized as having properties which make it an excellent white pigment. By 1912, TiO_2 began to replace lead oxide in paint.

Hunter's Process was used in three commercial plants that operated between the 1950's and 1992; however, the process proved difficult to scale up.

In the 1930's, Dr. Wilhelm Kroll invented the first viable, large-scale industrial method for reducing titanium — a production process that bears his name. The Kroll process uses magnesium as a reducing agent, and while the process can yield large amounts, it leaves a chloride residue and does not recover unreacted magnesium metal.

The emergence of vacuum distillation to remove that contamination and improve process economics overcame the last significant barrier to producing mass quantities of commercially pure titanium. Today, the Kroll process with vacuum distillation is the most widely used method of winning the metal from the ore.

At the Denver International Airport, sculptor David Griggs' *Dual Meridian* features what is believed to be the largest titanium arch in the world. It vaults over the international concourse. It connects two sides of the sculpture that honors railroads on one side and a vision of the future of transportation on the other. Although it measures 139 feet it weighs only 1400 pounds.

Sponge First: How Titanium Is Produced

To produce pure titanium — or sponge — rutile ore is mixed with coke or tar and chlorine gas and heated to form titanium tetrachloride ($TiCl_4$), a colorless liquid. The $TiCl_4$ is then reacted in the Kroll process, which uses magnesium as a reducing agent under an inert atmosphere. The resultant metal is known as “sponge” for its resemblance to the texture of ocean sponge.

The metal sponge then typically vacuum distilled to remove the excess magnesium chloride and unreacted magnesium metal, which are recycled. The pure titanium sponge must meet stringent specifications to assure control of the ingot’s composition.

Pure titanium exists in two crystallographic forms. The first is alpha, stable up to $1620^{o}F$ ($880^{o}C$), at which point it transforms to the beta phase, which is stable to the melting point. As alloying elements are added to pure titanium, they change the temperature at which the phase transformation occurs and the amount of each phase present, and therefore the characteristics of the metal.

A flute maker from Vermont is crafting the world’s first titanium flute, which has the advantages of light weight, durability and beauty, as well as acoustical advantages. The metal is ideally suited to high audio frequencies, as its acoustical response is extremely fast and its natural resonance is much higher than any other material in use today.

The family of titanium alloys offers a full range of strength properties from the highly-formable, lower strength to the very high-strength. Most of the alpha-beta and beta alloys can provide a myriad of strength-ductility property combinations via alloy heat treatment and/or composition. With the wide selection of titanium alloys available, optimum choice for a given environment is almost always possible.

Once the sponge is crushed and mixed with alloying elements, melting to ingots, which weigh up to 30,000 pounds, is the next step.

For Vacuum Arc Remelting, typically used for aerospace applications, the titanium sponge and alloying elements are pressed into briquets which are welded together to form an electrode. In the VAR furnace, the electrode is “consumable melted.”

A VAR second melt insures homogeneity of the ingot for industrial purposes; triple melting is used for all metal destined for aerospace use.

The alternative sponge melting process uses a cold hearth furnace to produce ingots to fulfill industrial requirements, or as feedstock for subsequent VAR melts. Here, the crushed sponge and alloying elements can also be mixed with inexpensive recycled titanium scrap before melting, to reduce costs.

In cold hearth melting, the titanium mixture is melted by either electron beams or by plasma arc torches. The metal flows across the cold hearth, where impurities sink to the bottom or are evaporated. Cold hearth melting is the preferred method for producing clean titanium for aerospace applications and combination cold hearth/ VAR melts can eliminate inclusions and defects that even triple VAR melting cannot remove.

Because cold hearth melting can use a high percentage of scrap, it produces affordable titanium for industrial and commercial uses.

VAR ingots and cold-hearth melted, cast slabs are pressed or rotary forged into slabs (rectangular shapes) or billets (rough round bar or various other shapes).

Common processing techniques create mill products — basic structural shapes with desired properties that maximum metal utilization. All mill products are available in the spectrum of alloys and grades.

Casting is an advanced technology for forming near-net shapes. It offers greater design freedom and significantly reduces the need for expensive machining or fabrication to attain the desired shape. Investment casting can be used to create large, tolerance-critical parts such as heat shields, fan frames and missile components, as well as smaller parts such as valve bodies.

Commercial casting began in the late 1960's and today the technology has matured to routinely supply critical gas turbine engine, air frame, chemical process and marine products.

Titanium powder technology may offer lower costs in the manufacture of near-net shapes and, with the potential of lower cost powder, it could open a wider range of applications.

Conventional metal processing tools and procedures can be used to form, machine and weld titanium and its workability is comparable to that of stainless steel.

The moon has a surprisingly high titanium content. In fact, Apollo 15 astronauts spotted it in rock samples immediately, as Dave Scott remarked to Jim Erwin: "Hey look at this. This one is loaded with titanium!"

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