Elements of Gr. 13	Unique Property	Applications
Boron	Lewis acid ^{10}B- High Nuclear cross section for thermal neutrons	Nuclear reactors- control rods Lewis acid, BNCT
Aluminium	Light metal Surface passivity Good strength to weight ratio and conductivity m.p. 660.3 °C	Bulk usage: Airplanes, ships, cars, trains $AlCl_3$: Friedel Crafts rxn MAO: In olefin polymerization
Gallium	Liquid metal m.p.29.77 °C	Gallium Arsenide solar cells Gallium nitride LED
Indium	Low melting soft solid (m.p.156 °C)	ITO production of transparent conductive coatings
Thallium	Poison, non metallic	The poisoner's poison“ (tasteless , odorless)

Chemistry of Aluminium

More than its compounds, the bulk usage of aluminium, especially its alloys dominate the industry

- Lightest metal; also relatively inexpensive metal .
- Tin was 19,830 USD/Metric Ton, zinc was 2,180 USD/MT and aluminium was 1,910 USD/MT
- **Third most abundant element on the earths crust**: combined in 270 minerals
- Low density and ability to resist corrosion by passivation.

Pure aluminium has about one-third the density and stiffness of steel.
The yield strength of pure aluminium is 7–11 MPa, while aluminium alloys have yield strengths ranging from 200 MPa to 600 MPa. Yield strength of mild steel is 250 Mpa while that of high strength alloy steel is 690 Mpa

A yield strength or yield point of a material is defined as the stress at which a material begins to deform plastically. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed. (Mpa = megapascal = 145psi)

Three main reasons why aluminium *alloys* are used instead of pure aluminium

- Increased strength to weight ratio over pure aluminium.
- Increased stress corrosion cracking and fatigue resistance.
- Improved stiffness and resistance to bending.

10 Differences Between Aluminum and Stainless Steel

1.Strength to weight ratio. Aluminum is typically not as strong as steel, but it is **almost one third of the weight**. This is the main reason why aircrafts are made from Aluminum.

2.Corrosion. Stainless steel is made up of iron, chromium, nickel, manganese and copper. The chromium is added as an agent to provide corrosion resistance. Aluminum has a high oxidation and corrosion resistance mainly due to its **passivation layer**.

3.Thermal Conductivity. Aluminum has a much **better thermal conductivity** (conductor of heat) than stainless steel. One of the main reasons it is used for car radiators and air conditioning units.

4.Cost. Aluminum is much cheaper than stainless steel.

5.Workability. Aluminum is fairly soft and easier to cut and form. Due to its resistance to wear and abrasion, Stainless can be difficult to work with.

6.Welding. Stainless is relatively easy to weld, while Aluminum can be difficult.

7.Thermal properties. Stainless steel can be used at much higher temperatures than Aluminum which can become very soft above about 400 degrees.

8.Electrical Conductivity. Stainless steel is a really poor conductor compared to most metals. Aluminum is a **very good conductor of electricity**. Due to its high conductance, light weight, and corrosion resistance, high-voltage overhead power lines are generally made of aluminum.

9.Strength. **Stainless steel is stronger than Aluminum** (provided weight is not a consideration).

10.Effect on Foods. Stainless steel is less reactive with foods. Aluminum can react to foods which may affect color and flavor.

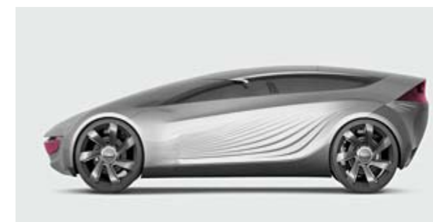
Providing strength in

Stationary infrastructure

Steel

Steel	**2013**	**1528 (MMT)**

Modes of transportation



Aluminium

Aluminium	**2012**	**45 (MMT)**

1million metric ton (mmt) =1 000 000 000 kilograms (10 crore kg!)

Talgo train does Delhi-Mumbai in under 12 hours

Septermber 10, 2016

Talgo beat Gatimaan, Rajdhani and Shatabdi trains to clock the highest ever speed on Indian tracks -180kmph.

Pure Aluminium has low specific gravity, good corrosion resistance and excellent thermal and electrical conductivity it is too weak (~10 Mpa) and ductile to be used on its own.

In 1906 Dr Alfred Wilma, a German metallurgist, discovered that aluminium alloyed with copper and heat- treated correctly could be made far stronger. The alloy of aluminium with copper is called Duralumin . These alloys have typically low specific gravity (around 2.7) and high strength (450 MPa).

Four-digit number	Alloying element(s)
1XXX	aluminium of 99% minimum purity
2XXX	aluminium-copper alloys
3XXX	aluminium-manganese alloys
4XXX	aluminium-silicon alloys
5XXX	aluminium-magnesium alloys
6XXX	aluminium-magnesium-silicon alloys
7XXX	aluminium-zinc-(magnesium) alloys
8XXX	miscellaneous, e.g. Aluminium-lithium alloys

Alfred Wilma's discovery was patented and implemented in production at Duerener Metallwerke AG plant. In 1909, the plant officially presented its products: the ultra-strong alloy, duralumin (aluminium, copper (1.3%), magnesium (2.8%) and manganese (1%)). In fact, this metal became the base for development of aircraft alloys.
(Wright brothers 1903 flew the first flight aircraft made of giant Spruce' wood)

The advantages of Duerener 'aluminium' were appreciated by Professor of Thermal Dynamics, and Aircraft Manufacturer of Aachen University, Hugo Junkers. More than once he had attempted to assemble an all-metal airplane: On December 15th, 1915 testing of the J1 glider made of sheet iron. But the representatives of the military administration 'rejected' the airplane, calling it 'a tin donkey': J1 – too heavy, with a low climbing capacity and maneuverability, and did not comply with the requirements of military aviation. Junkers understood that the major 'culprit' of the failure was metal. He needed an alternative to thick (up to 1 mm) iron sheets. And this alternative was found!

Duralumin met all the requirements of Hugo Junkers: high strength, forgeability, and the incredible lightness for a metal were very much to the point. As soon as in 1917, the J.7 fighter entirely built of the 'light' metal took off from Adlershof airfield.

In the same year, production of Junk J.1 military airplanes was started; they were ordered by Germany for participation in the First World War. During the military campaign, duralumin completely proved Junkers' calculations: The metal reliably protected the pilot from bullets and shells. Junk J.1 airplanes were named 'flying tanks'. There is a recorded case when duralumin sustained 480 bullet shots on the wings and fuselage, and the airplane not only completed the combat mission, but also successfully landed at base. Germans kept the composition of Duralumin a military secret!

In 1918, on the insistence of the manufacturer A.N. Tupolev and Professor of Moscow State University N.E. Zhoukovsky, the Central Aerohydrodynamics Institute (CAHI) was established in Russia .In Spring 1922, a significant event happened at CAHI: The fuselage of a shot-down Junkers D.I fighter – a priceless trophy from the viewpoint of domestic aviation – was delivered to the Institute. A separate 'Material Testing Division' group was organised, in order to study the composition of the airplane metal covering. The researchers did not just determine the formula of duralumin but managed to develop a stronger alloy modification, able to compete with foreign developments. The results of their work were sent to the Brass and Copper-Rolling Plant of Kolchougin Co.

In late 1922, the plant started production of 'kolchougaluminium' – the first Soviet high-strength alloy. And as soon as the following year, Tupolev's design department was provided with the complete 'aircraft' set: sheet, corrugated, and shaped kolchougaluminium. Work was started to create a competitor to Junkers, the Soviet airplane AN-2, which was presented on May 28th, 1924.

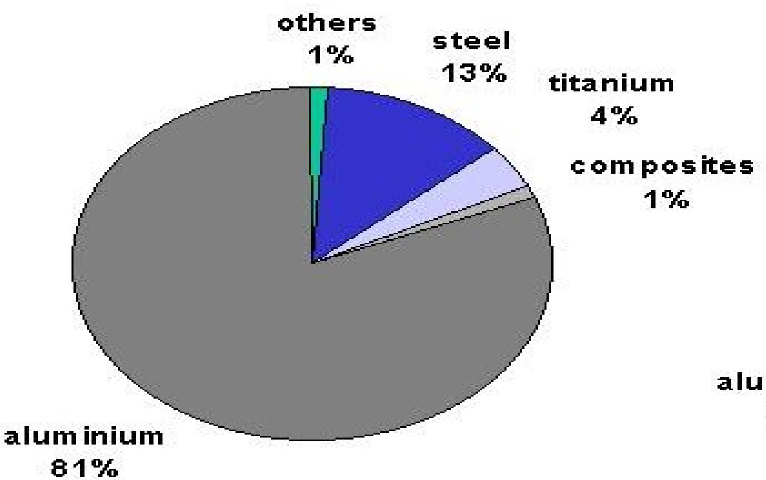
Aluminium played an important role during the Second World War. The invaluable contribution in establishing the defence power of the Soviet Army was made by the Urals Aluminium Smelter (UAZ). The first stage of UAZ was commissioned in September 1939.

At present, aluminium is used in the aviation industry everywhere in the world. From two thirds to three quarters of a passenger plane's dry weight, and from one twentieth to half of a rocket's dry weight accounts for the share of aluminium in airborne craft. The casing of the first Soviet satellite was made of aluminium alloys. The body casing of American 'Avantgarde' and 'Titan' rockets used for launching the first American rockets into the orbit, and later on – spaceships, was also made of aluminium alloys. They are used for manufacturing various components of spaceship equipment:

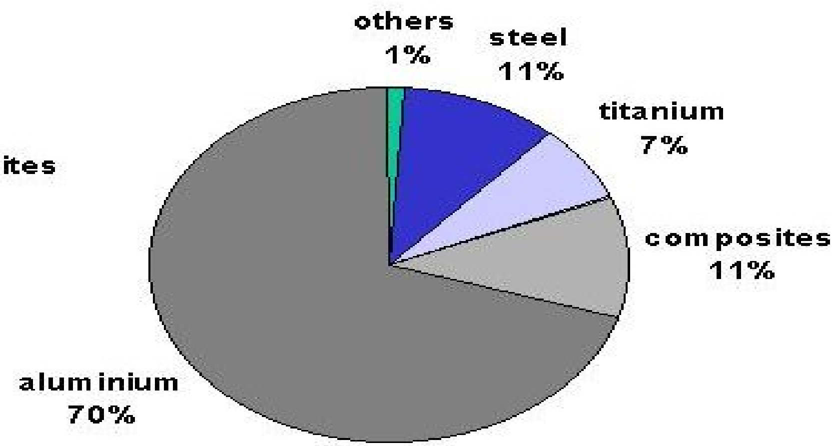
Aluminium alloys in aerospace

BOEING

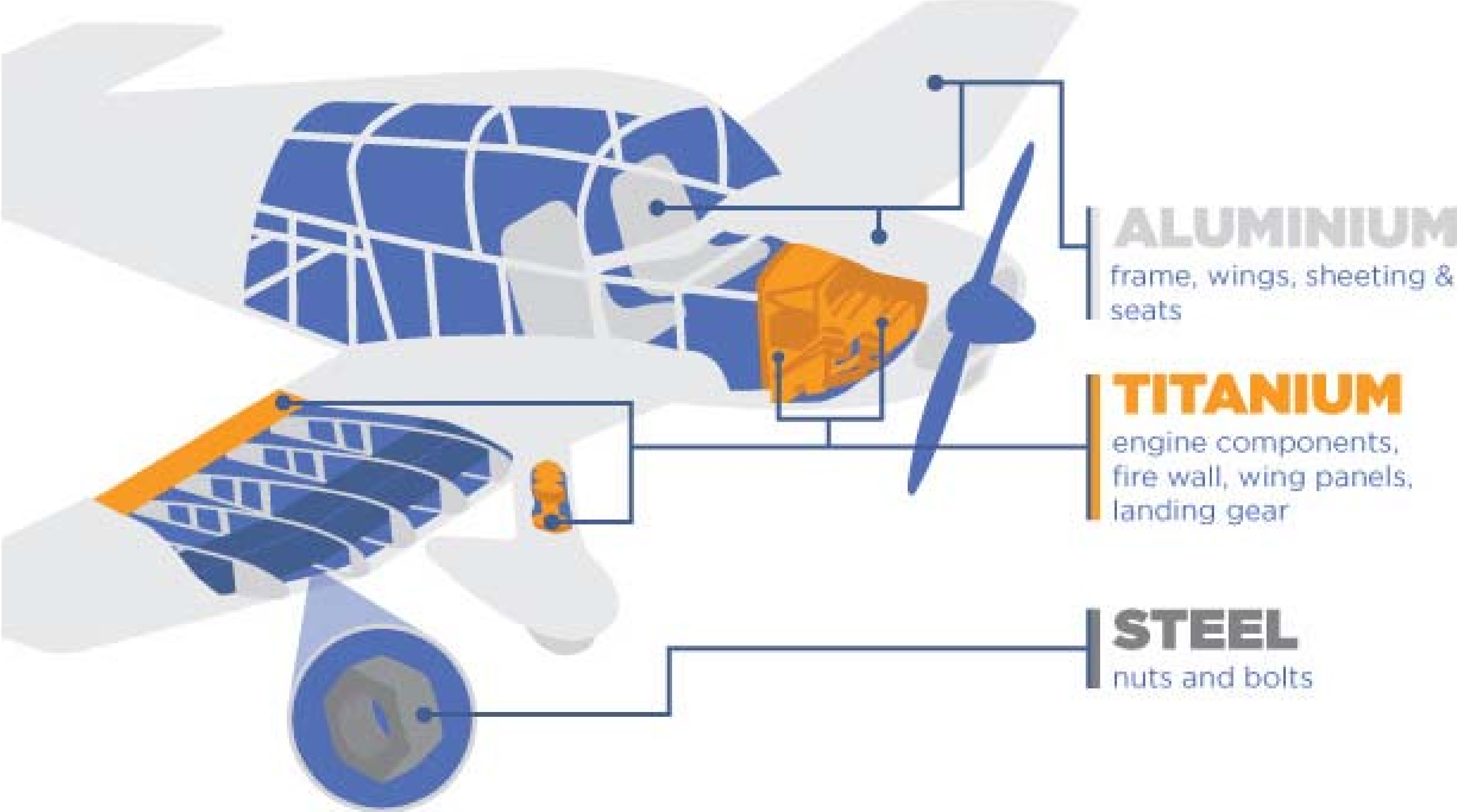
747



777



The most commonly used aluminium alloys for airframe construction are the precipitation hardening alloys in the 2XXX and 7XXX series


ALUMINIUM
frame, wings, sheeting & seats
TITANIUM
engine components, fire wall, wing panels, landing gear
STEEL
nuts and bolts

Fuselage skin, slats, flaps - areas primarily loaded in tension - **Aluminium alloy 2024** (Aluminium & copper) - Good fatigue performance, fracture toughness and slow propagation rate.

Frames, stringers, keel & floor beams, wing ribs - Aluminium alloy 7075 (Aluminium & zinc) - High mechanical properties and improved stress corrosion cracking resistance.

Wing upper skin, spars & beams - **Aluminium alloy 7178** (Aluminium, zinc, magnesium & copper) - High compressive strength to weight ratio.

Aluminium alloys in shipbuilding

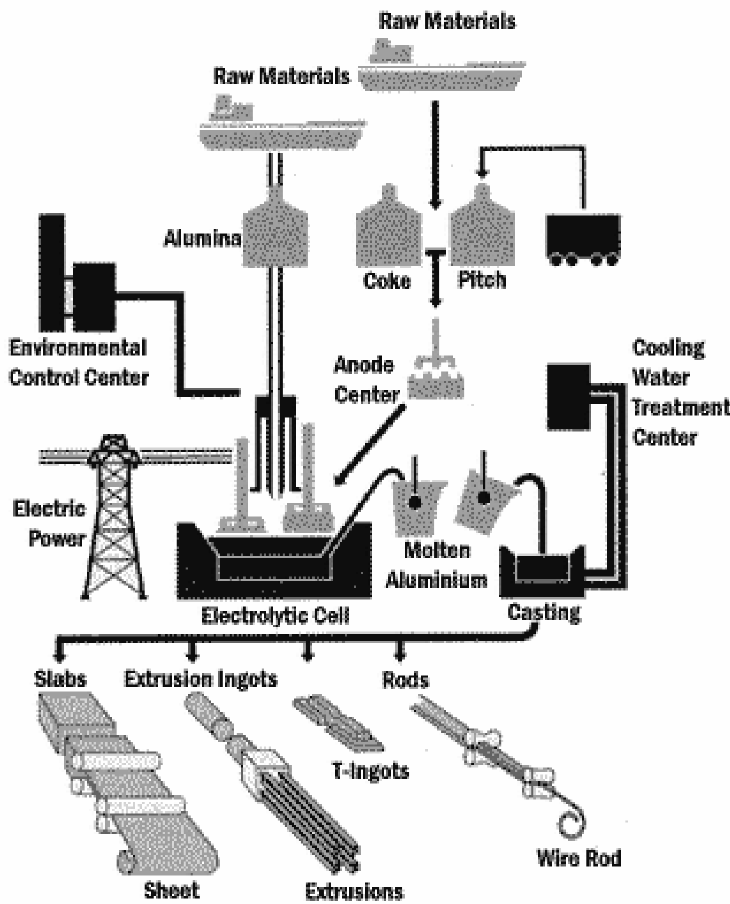
Throughout the years, steel was the most popular material in shipbuilding. Though steel has many advantages, its major drawback is its considerable weight. Construction of vessels with more and more carrying capacity made them bulky and led to poor control. For example, during the past century since 1910 the maximum weight of vessels increased more than twice: from 46,000 t ('Titanic') to 109,000 ('Golden Princess'). The weight factor determines the vessel speed and the transported payload weight. And the faster the vessels and the more weight they carry, more the profits. This was what motivated the studying of aluminium and its capabilities. It is known that using the 'light metal' allows reducing the ship weight by over 50%.

The first studies of aluminium alloy properties were initiated in the very beginning of the century, but only by the forties did the researchers who studied the issue of aluminium corrosion in seawater discovered that adding a small amount of magnesium and silicon, made aluminium resistant to salt water. **Alloy 5083** is considered the base alloy of the shipbuilders. Although this alloy is often called the 'shipbuilding' alloy, it is also widely used in many other industries. Alloy 5083 initially won popularity in shipbuilding thanks to its properties, such as high strength, corrosion resistance, good mouldability, and excellent welding characteristics.

6) Application of Al alloys

- Aluminum alloys are widely used for **aeronautical** applications because of high strength weight ratio.
- For **automobiles** for reducing weight of the vehicle thus reducing fuel consumption.
- For applications as **electrical conductors** including overhead transmission lines.
- **House hold and consumer** items such as utensils.
- Used as **sacrificial anode**.
- **Marine** applications. For **surface transport** such as fittings in railway coaches and buses.
- Aluminum is also used in making **windows**, doors and roofs of factories.
- Also in **Sporting Equipments**.

Hall-Héroult electrolytic process

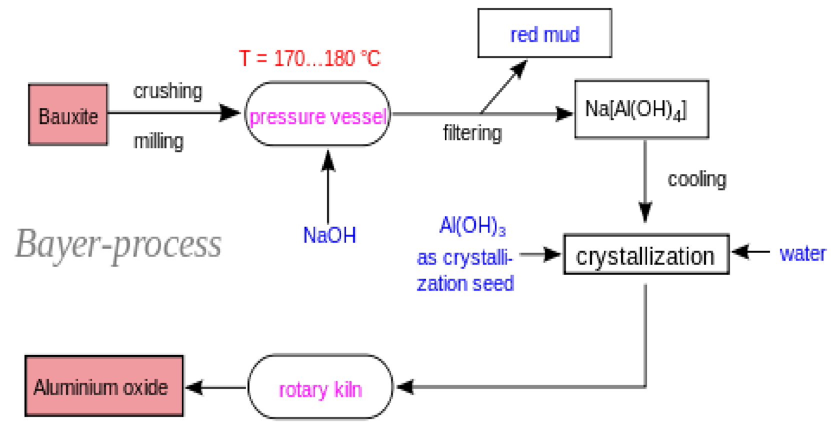


Primary aluminum is produced using the Hall-Héroult electrolytic process. Carried out in large electrolytic cells called pots with a direct electric current input of up to 280,000 amperes and about 5 volts. carbon blocks are placed to form a cathode. Steel collector bars are inserted into the cathode blocks to carry current away from the pot.

Molten cryolite (sodium-aluminum fluoride Na_3AlF_6) is placed in the cavity formed by the cathode blocks. Anodes, also of baked carbon, are immersed in the cryolite to complete the electric path. Anodes may be either pre-baked in a separate process and attached to connecting rods for immersion in the bath (termed prebake design cells), or may be formed through self-baking from coal-tar and petroleum coke paste that is fed into the top of a steel casing above the cell . Alumina (Al_2O_3) is fed in powder form into the pots and is dissolved in the cryolite bath. Molten aluminum is evolved while the anode is consumed:

Al2O3 + 3/2C => 2Al +3/2 CO2

The **Bayer process** is the principal industrial means of refining bauxite to produce alumina (aluminium oxide). Bauxite, the most important ore of aluminium, contains only 30–54% aluminium oxide, (alumina), Al_2O_3, the rest being a mixture of silica, various iron oxides, and titanium dioxide. The aluminium oxide must be purified before it can be refined to aluminium metal



In the Bayer process, bauxite is digested by washing with a hot solution of sodium hydroxide, NaOH, at 175 °C, under pressure. This converts the aluminium oxide in the ore to soluble sodium aluminate, $2NaAlO_2$,

$Al_2O_3 + 2\ NaOH \rightarrow 2\ NaAlO_2 + H_2O$

lime is added here, to precipitate the silica as calcium silicate. The solution is clarified by filtering off the solid impurities, The alkaline solution was cooled and treated by bubbling carbon dioxide into it, through which aluminium hydroxide precipitates. Another method is seeding the supersaturated solution with high-purity $Al(OH)_3$ crystal:

$2\ NaAlO_2 + CO_2 \rightarrow 2\ Al(OH)_3 + Na_2CO_3 + H_2O$

$2\ H_2O + NaAlO_2 \rightarrow Al(OH)_3 + NaOH$

when heated to 980°C , the aluminium hydroxide decomposes to aluminium oxide

$2\ Al(OH)_3 \rightarrow Al_2O_3 + 3\ H_2O$

The left-over NaOH solution **(Bayer liquor)** is then recycled. This, however, allows **gallium** and vanadium impurities to build up in the liquors, so these are extracted.

Thermite Process

Thermite process is useful method for the welding of broken metal parts especially steel railway lines. When aluminum powder reacts with iron oxide or chromium oxide, a large amount of heat is released and about a temperature of 3500 °C is attained which is enough to weld the metallic parts required to be joined.

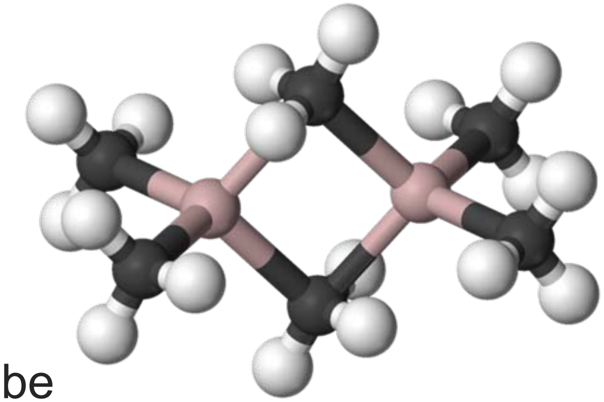
Thermite is a pyrotechnic composition of metal powder fuel and metal oxide. When ignited by heat, thermite undergoes an exothermic reduction-oxidation (redox) reaction. Most varieties are not explosive but can create brief bursts of high temperature in a small area.

$$Fe_2O_3 + 2\,Al \rightarrow 2\,Fe + Al_2O_3$$

a copper thermite reaction using copper oxide and elemental aluminium can be used for creating electric joints in a process called cadwelding that produces elemental copper (it may react violently):

$3\,CuO + 2\,Al \rightarrow 3\,Cu + Al_2O_3$

Trimethyl and Triethyl Aluminium



TMA is prepared via a two-step process that can be summarized as follows:

$2\ Al + 6\ CH_3Cl + 6\ Na \rightarrow Al_2(CH_3)_6 + 6\ NaCl$

TMA is mainly used for the production of methylaluminoxane, an activator for Ziegler-Natta catalysts for olefin polymerisation.

$$4\ Al + 6\ MeCl \longrightarrow Al_2Cl_2Me_4 + Al_2Cl_4Me_2$$

$$3\ Al_2Cl_2Me_4 + 6\ Na \longrightarrow 2\ Al_2Me_6 + 2\ Al + 6\ NaCl$$

$$TiCl_4 + Al_2Me_6 \longrightarrow MeTiCl_3 + AlClMe_2$$

Controversy: Alumina in the atmosphere
As an additive to aviation fuel.
Trimethyalminium (TMA) is easily capable of
producing long white trails of aluminium
oxides aerosols – aka Chemtrails

Ziegler-Natta Catalysis of Alkene Polymerization

A typical Ziegler-Natta catalyst is a combination of $TiCl_4$ and $(CH_3CH_2)_2AlCl$, or $TiCl_3$ and $(CH_3CH_2)_3Al$.

The modern catalyst combinations (Kaminsky catalysts) include a metallocene and methyl aluminium compounds.

Ziegler's Discovery

- **1953 K. Ziegler, E. Holzkamp, H. Breil & H. Martin**
- Angew. Chem. **67**, 426, 541 (1955); **76**, 545 (1964).

$$Al(Et)_3 + NiCl_2 \xrightarrow[\text{100 atm, 110 C}]{=} CH_3CH_2CH{=}CH_2 + Ni + AlCl(Et)_2$$

+ Ni(AcAc) Same result

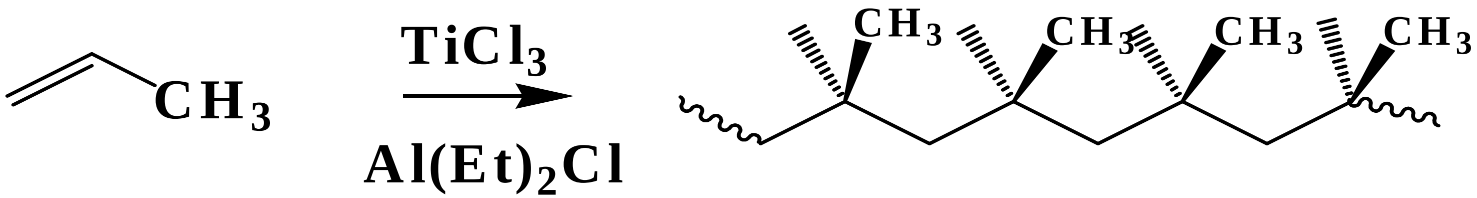
$$Al(Et)_3 + TiCl_4 \xrightarrow[\text{1 atm, 20-70 C}]{=} \sim\sim CH_2CH_2 \sim\sim$$

"linear"

Mw = 10,000 - 2,000,000

Natta's Discovery

- **1954 Giulio Natta, P. Pino, P. Corradini, and F. Danusso**
- J. Am. Chem. Soc. 77, 1708 (1955) Crystallographic Data on PP
- J. Polym. Sci. 16, 143 (1955) Polymerization described in French

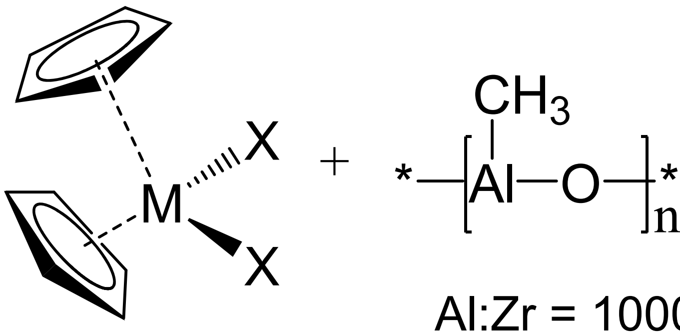


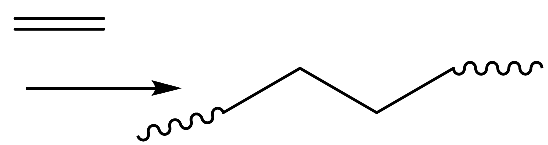
Isotactic

Ziegler and Natta won Nobel Prize in 1963

Kaminsky Catalyst System

W. Kaminsky et.al. Angew. *Chem. Eng. Ed*. **19**, 390, (1980); Angew. Chem. **97**, 507 (1985)



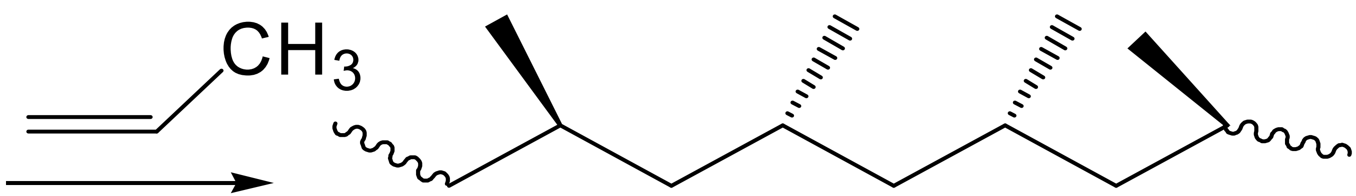


Al:Zr = 1000

M = Ti, Zr, Hf

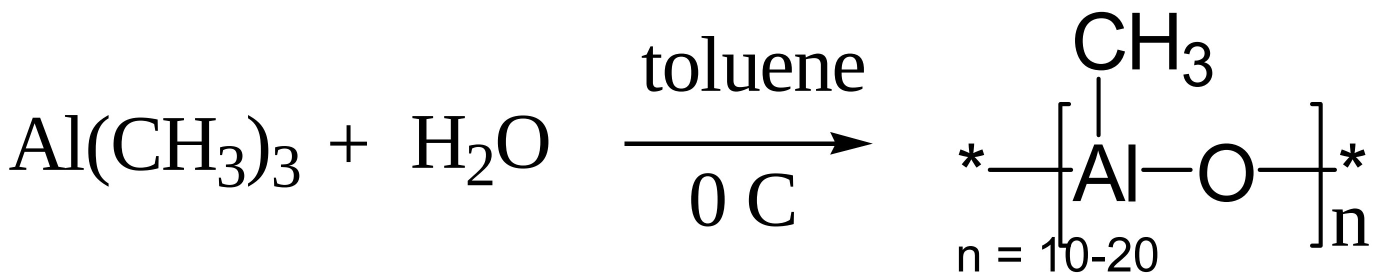
Linear HD PE

Activity = 10^7 g/mol Zr



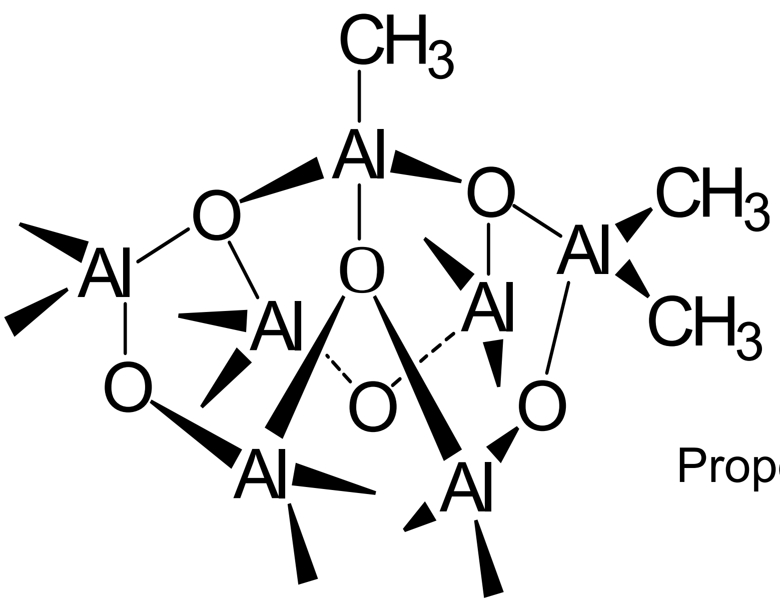
Atactic polypropylene

Methylaluminoxane: the Key Cocatalyst



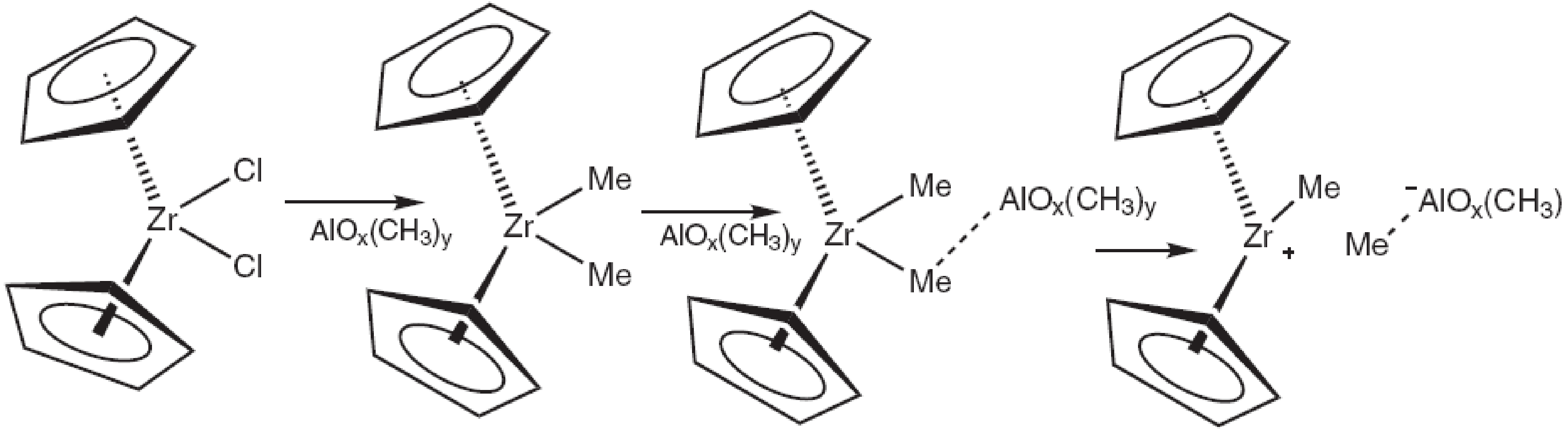
MAO

Methylaluminoxane, commonly called **MAO**, is a white solid with the general formula $(Al(CH_3)O)_n$.



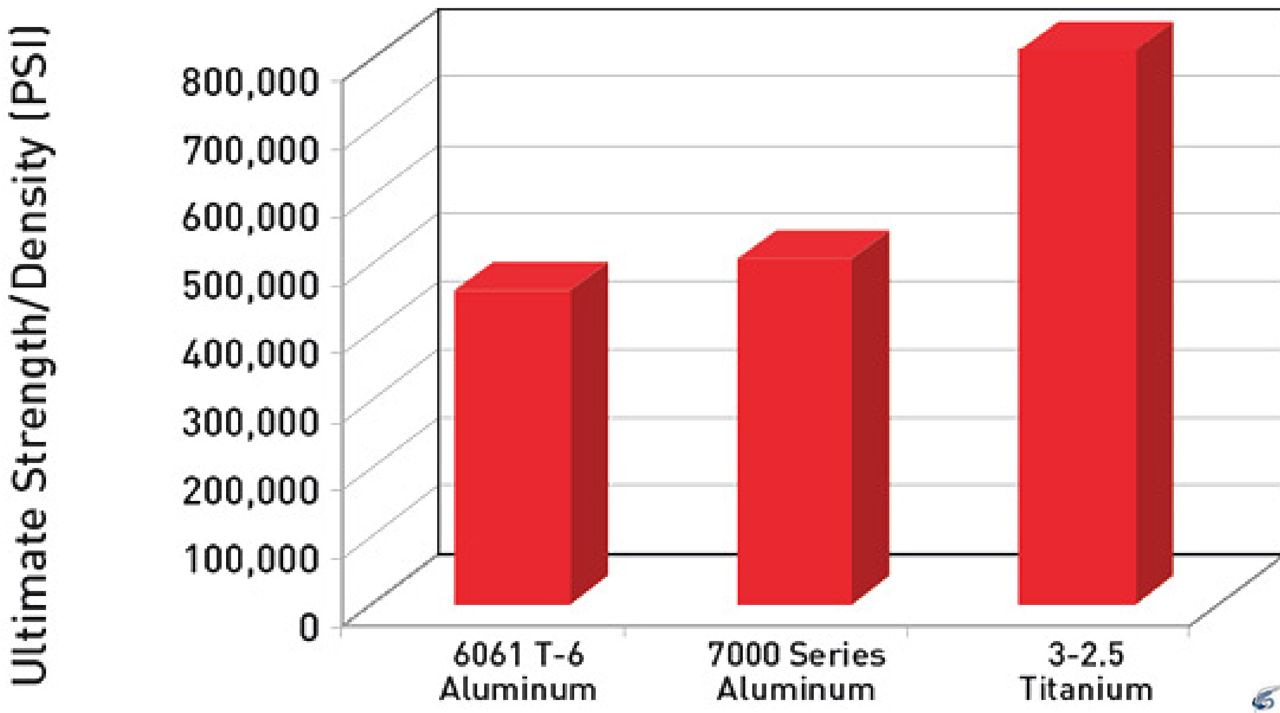
Proposed structure

Action of MAO as cocatalyst



Scheme 17.1 Activation of Cp_2ZrCl_2 with MAO

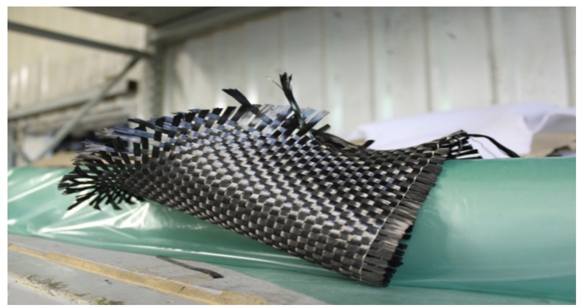
Titanium has the Highest Strength-to-Weight Ratio of Any Metal on Earth[1-4]

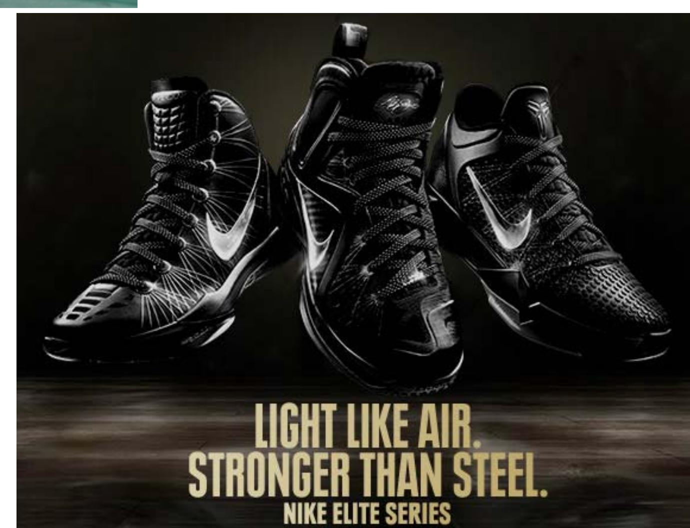


There are two types of titanium frame — pure and alloy. Pure titanium is about 99% pure while titanium alloy, also called “bendable titanium,” is about 75% pure with 25% of other metals such as nickel or copper added. Both kinds of titanium eyewear frame will be lightweight, durable and strong, but pure titanium frames, which are typically more expensive, will exceed the memory titanium in all of these qualities.

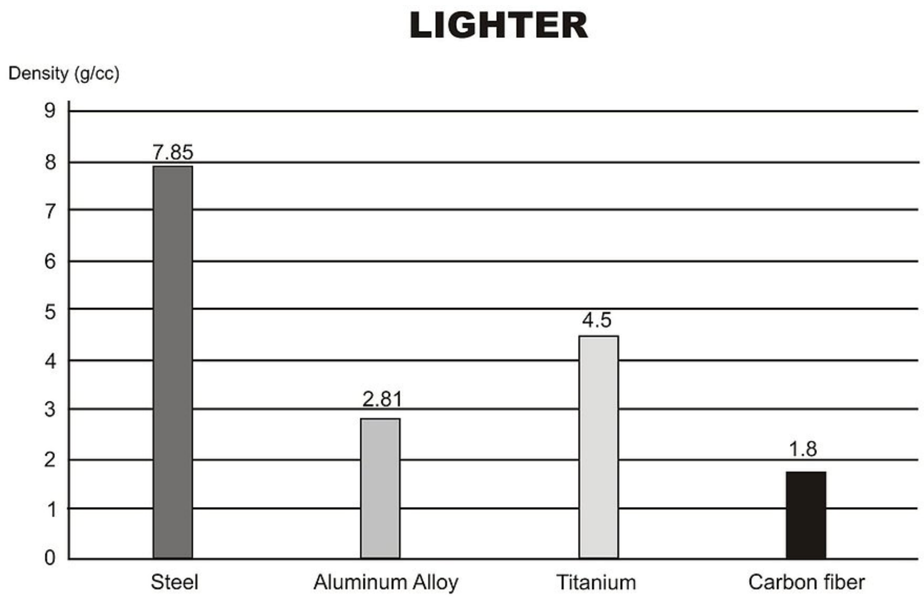
New kid in the block: Carbon fiber

Carbon atoms are bonded together in crystals that are more or less aligned parallel to the long axis of the fiber as the crystal alignment gives the fiber high strength-to-volume ratio (making it strong for its size). Several thousand carbon fibers are bundled together to form a tow, which may be used by itself or woven into a fabric.



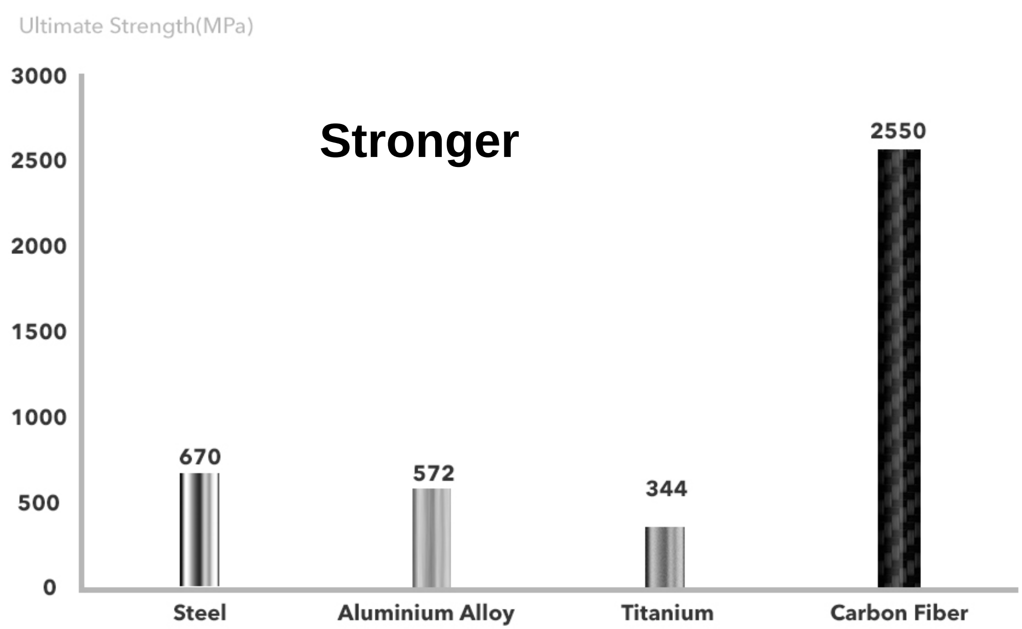


Carbon fiber versus aluminum



if you have a structure that can take advantage of the directional properties of carbon fiber, like a bicycle wheel or frame tube, or a helicopter blade, where certain pieces of it can be aligned with the flexing or stress that the part will see, you can get *up to* about a 30% weight savings over aluminum.

Environmental conditions have a great effect on carbon composites. Once the temperature goes up above 150 F., carbon fiber epoxy composite properties will be reduced somewhat whereas the steel and aluminum properties will remain essentially the same. High humidity with heat will have an even greater effect.

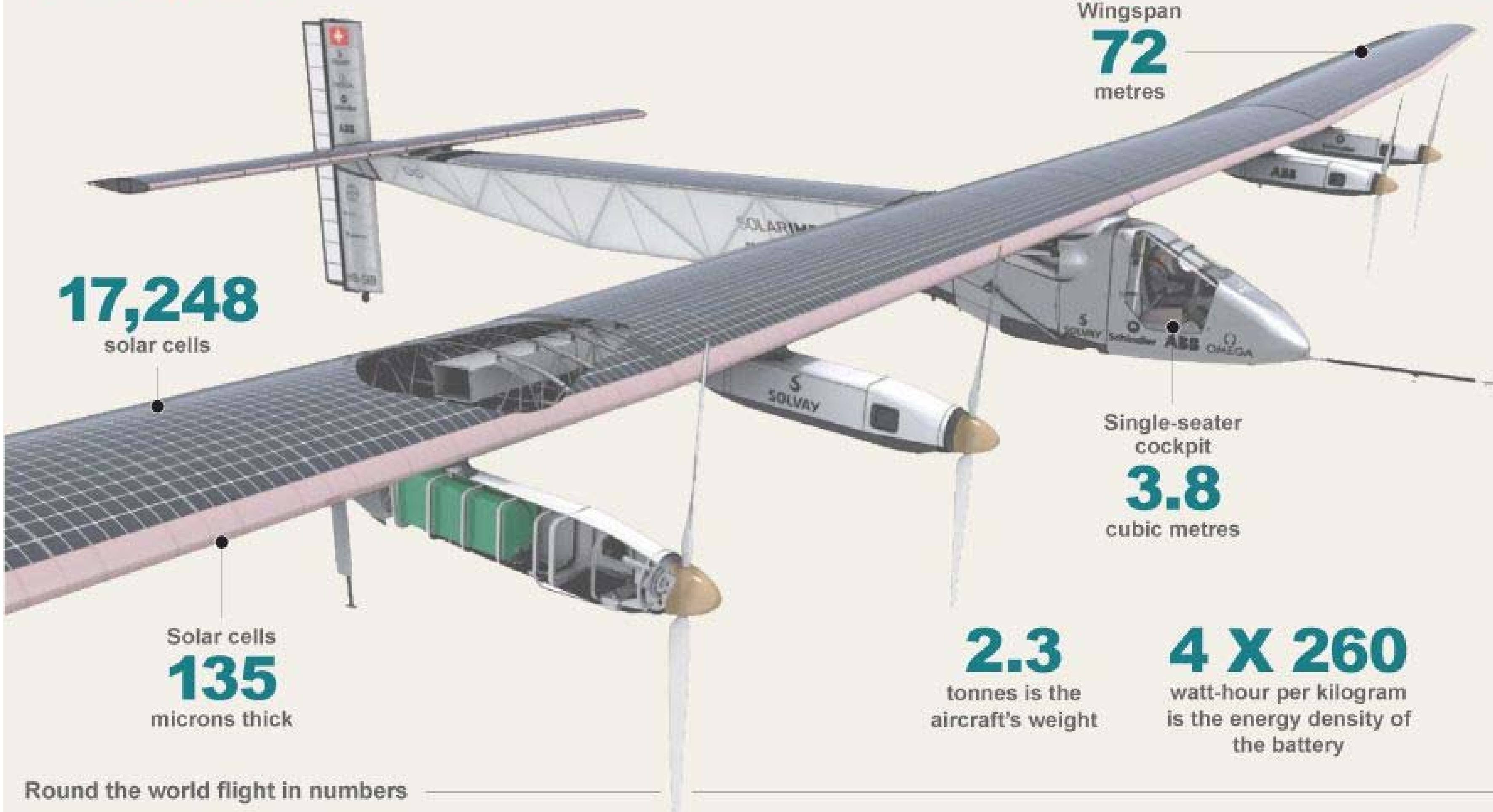


Solar impulse 2- A solar plane

Solar Impulse 2 was built to take up the challenge of achieving the first round-the-world solar flight. This aeroplane uses zero fuel. Solar Impulse is a Swiss-made, long-range experimental solar-powered aircraft. It is led by Swiss businessman André Borschberg and Swiss aeronaut Bertrand Piccard

This revolutionary single-seater aircraft **made of carbon fiber** has a 72 meter wingspan (larger than that of the Boeing 747-8I) for a weight of just 2,300 Kg, equivalent to that of a car.
The 17,000 solar cells built into the wing supply four brushless electric motors with renewable energy.
During the day, the solar cells recharge lithium batteries weighing 633 Kg (2077 lbs.) which allow the aircraft to fly at night and therefore to have virtually unlimited autonomy.

Solar Impulse 2



Round the world flight in numbers

- **2** pilots, Bertrand Piccard and Andre Borschberg
- **1** aircraft: Solar Impulse 2
- **0** fuel on board
- **32** thousand kilometres journey
- **600** flying hours (approximately)
- **12** legs (approximately), some lasting more than five days and nights
- **5** month mission, March to August 2015
- **140** people in the support team