

sunrise
energy metals



ADVANCED LIGHTWEIGHT ALLOYS



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SCANDIUM FOR LIGHTWEIGHT ALLOYS

Scandium is a metallic element with atomic number 21. While it is a transition metal, it sometimes is classified as a rare-earth element. While scandium is not particularly rare in the earth's crust (31st most abundant), it is very rare to find in concentrations over 100ppm.

While the potential applications of scandium are broad, Clean TeQ has focussed on two key areas: aluminium scandium alloys for light-weighting the global transport industry and the use of scandium in solid oxide fuel cells.

The lack of any reliable supply of scandium has been the limiting factor in development of this market. However, this has the potential to change rapidly as scandium from primary mine production is brought on stream and expanded.

Aluminium-Scandium Alloys

While the solid oxide fuel cell industry has been the dominant consumer of scandium in recent years, scandium's greatest value lies in the functional properties it imparts as an alloy in aluminium. Aluminium-scandium (AlSc) alloys represent one of the largest untapped opportunities for delivering lightweighting solutions to the global transport sector.

Growing transport sector interest in AlSc alloys arises from:

- Legislation setting tougher fuel efficiency targets and CO2 limits globally;
- Aluminium's comparative benefits as a strategic lightweighting material; and
- Scandium's potent strengthening effect in a broad range of aluminium alloys.

Major aluminium players and leading-edge transport sector companies are aware of the lightweighting opportunities that AlSc alloys offer. In fact, many of the original Al-Sc alloys were first developed in the 1960s, specifically for aerospace use. Adoption has been held back, however, by availability and affordability. As one of the highest-grade sources of naturally occurring scandium in the world, the Sunrise Project can transform value in use considerations across the entire global aluminium value chain.

Scandium provides significant benefits to a broad range of aluminium alloys in a diverse set of metal offerings. However, a range of physical and economic parameters need to be considered in optimising each application and the associated manufacturing process.

| | Aerospace | Automotive | Rail | Marine |
|------------------------------|-----------|------------|------|--------|
| Sheet | | | | |
| Extrusions | | | | |
| Castings | | | | |
| Forging Weld | | | | |
| Wire | | | | |
| Additive Layer Manufacturing | | | | |

The scandium marketing matrix for global transportation

Sunrise will make quality scandium raw materials reliably available in commercially useful quantities and at much lower prices. To further improve the value proposition of AlSc alloys, Clean TeQ is collaborating with partners to optimise the scandium content. Compositions that deliver the full suite of benefits with minimal scandium added will accelerate the deployment of AlSc alloys.

Aerospace

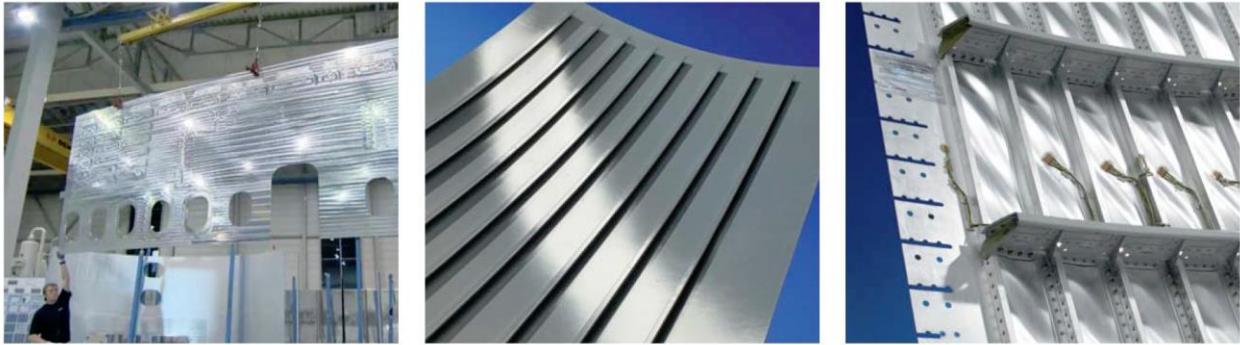
While AlSc alloys have been used in the aerospace industry for decades, their high price performance parts on military aircraft. However, over the last two decades a significant amount of development work has been undertaken on the use of AlSc alloys for commercial aircraft components. The high strength and weldability of AlSc alloys means that future aircraft can significantly benefit from their broader application, through fuel savings by reduced weight and manufacturing costs.

High Strength Sheet for Fuselage Skins

Airbus and Aleris have co-developed a high strength AlMgSc alloy¹ (AA5028) for use in fuselage skin on aircraft². 5028 offers weight reduction opportunities relative to incumbent alloys both directly and through superior weldability. AlMgSc formability properties also enable drop-in solutions and streamlining of the aircraft production line. This allows for a reduction in the “buy-to-fly” ratio, as less material is required in the finished component and manufacturing processes can be used to minimise material waste.

¹ Airbus and Aleris co-development of 5028 AlMgSc alloy: <http://www.france-metallurgie.com/31923/>

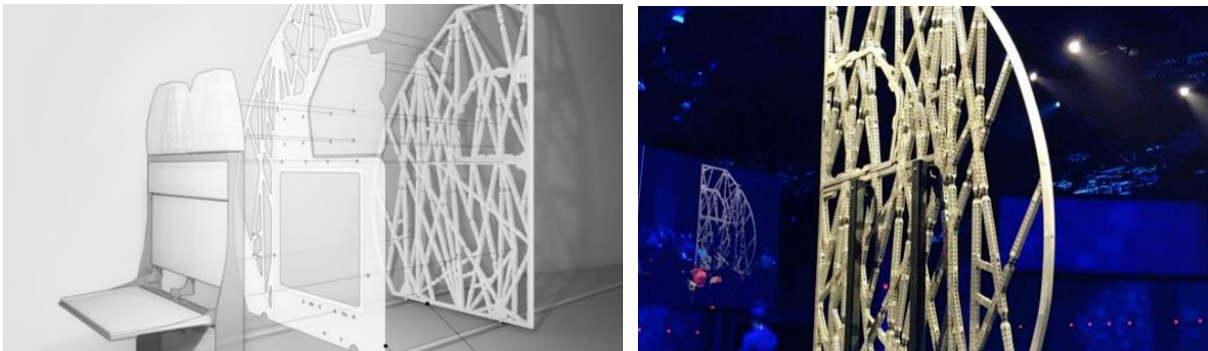
² Aleris: www.aleris.com; for more info on creep forming please see: <https://youtu.be/SP2s2dXMYd4>



Aleris creep formed AlMgSc fuselage skin component

Additive Manufacturing (3D Printing)

Airbus Group Innovations (AGI) is Airbus' global network of research and technology centres for future aerospace challenges. AGI is responsible for development, qualification and commercialisation of Scalmalloy®, a patented 3D printing AlSc powder and direct manufacturing concept used in the production of high strength components for Airbus' fleet of aircraft. Compared to all other aluminium alloys currently used in selective laser melting (a typical 3D printing process), Scalmalloy® offers outstanding mechanical strength values in combination with corrosion resistance, allowing the material's use without protective coatings.



3D Printed Scalmalloy® RP partition and Aleris creep formed AlMgSc part³

High Strength Extrusions

In January 2016, Clean TeQ entered a collaboration with Universal Alloy Corporation⁴ (UAC) and Deakin University for the development of higher strength and improved surface finish extruded parts for aerospace. The work was supported by a government grant and was completed in September. The 9-month program investigated model alloys series to determine the effect of scandium addition on strength and impact on extrudability. Results have been very encouraging and have paved the way for additional work at Deakin University to optimise the scandium addition and processing parameters, as well as largescale trials at UAC.

³ <http://www.airbusgroup.com/int/en/story-overview/Pioneering-bionic-3D-printing.html>

⁴ For more information on UAC's production facilities and extruded products, see: https://youtu.be/_xeBkx1gUgo

Welding Wire

Aluminium alloys that are both very strong and very weldable offer the prospect of substantial weight savings in future aircraft, for example by reducing or eliminating the need for rivets. While small additions of scandium can dramatically improve the weldability of a range of aluminium alloys, an alternative approach is to introduce scandium units into weldments via a filler wire. High strength, high fatigue resistance welds can be achieved without modification to the base alloys, resulting in stronger finished components with no change to the current production process. Ease and reliability (quality) of the welding process are additional benefits.

Automotive

The automotive industry is under considerable pressure to produce lighter vehicles with improved recyclability. For conventional cars, lighter materials of construction are often the only way to meet fuel efficiency and emission reduction targets. Additionally, electric vehicles need to find ways to offset the very substantial weight of the battery systems. Recyclability of material is also of key importance to the automotive industry as, unlike aerospace, this plays a much larger role in the total lifecycle cost of a vehicle. The combination of these factors has led to the automotive sector substantially increasing its use of aluminium, with 50% growth forecasted by 2020⁵.

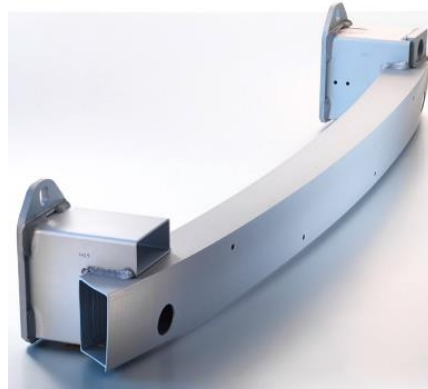
The need for stronger, more weldable and more formable aluminium is driving considerable automotive sector interest in scandium-containing alloys. Additionally, scandium is typically added as a trace material and can be used in normal alloy production processes, segregation of materials will be minimised. Clean TeQ is leveraging our experience of scandium in aerospace to fast track development of applications in automotive. Below are some examples of collaborations with key partners in the automotive industry to validate the benefits of aluminium-scandium alloys.

High Strength Extrusions for Body Frame & Crash Management Systems

Of utmost importance in the design of any vehicle is its ability to protect passengers against collisions on all sides. The internal skeleton of the car is made up of the main body frame with the crash management system (CMS) on the front and back of vehicle for crash protection.

The key feature of the CMS (e.g. bumpers, etc) is its ability to absorb energy without failure. The main body needs to have high strength to maintain structural integrity. Both strength and “ductility” (ability to absorb energy) are the key focus for materials used. Traditionally, these sections have been made from heavier steel components. Substitution with high strength aluminium offers significant weight reduction without compromising safety or ductility.

⁵ Please see the Arconic website: <http://www.arconic.com/global/en/what-we-do/automotive.asp>



Body Structure and Crash Management Systems⁶ produced for aluminium

High Strength Sheet for Panels

Aluminium has already been adopted in panels for some models by major car companies such as Ford, Jaguar Land Rover and Audi. Aluminium provides significant weight saving over traditional steel panels and much lower cost and higher recycle rates than carbon fibre alternatives, used in some high-end vehicles.



Aluminium panels for Ford's F150 manufactured by Novelis⁷

Aluminium panels for Ford's F-150 manufactured by Novelis⁷ Scandium can be used to promote wider adoption of aluminium in these applications. Scandium's potent strengthening effect allows thinner panels to be used, reducing weight. Where superior corrosion resistance is essential as well as increased strength, an adapted AlMgSc alloy may prove to be the optimal solution. Scandium also improves formability, which means panels can incorporate more complex features – a highly desirable benefit for car companies looking for differentiated aesthetics.

Castings

Casting is an important way to produce components with complex geometries, ranging from body nodes to wheels. One of the benefits of casting is the ability to reduce the number of parts required to assemble a complete vehicle, to achieve critical technical and commercial objectives.

⁶ Please see the Constellium website: <http://www.constellium.com/aluminium-products/automotive-structures>

⁷ <http://novelis.com/markets-we-serve/automotive/>



Aluminium cast parts for automotive⁸

Castable silicon-containing alloys are typically used to produce these components to the required specification. The automotive sector has great interest in designing new casting alloys that preserve or improve formability while increasing strength.

Solid Oxide Fuel Cells (SOFCs)

Fuel cells were invented over a century ago and have been used in practically every NASA mission since the 1960s. However, they have not gained widespread adoption until now because of their higher cost relative to other sources of baseload power. Solid Oxide Fuel Cells (SOFCs) hold the greatest potential of any fuel cell technology. With low cost ceramic materials and extremely high electrical efficiencies, SOFCs can deliver attractive economics.

SOFCs convert a fuel source (typically natural gas) and oxygen into electricity, water, carbon dioxide and heat. SOFC's use a hard ceramic material as a solid electrolyte between an anode and cathode, which, when subjected to high temperatures, catalyses the conversion of natural gas to energy. In the absence of scandium, the high temperatures quickly degrade the ceramic electrolyte, adding to the capital and maintenance costs of the units. The use of scandium in the solid electrolyte allows the system to operate at much lower temperatures than conventional SOFC's, lowering the costs and allowing the potential for wide spread adoption for distributed power generation.

⁸ <http://www.magna.com/capabilities/body-chassis-systems/innovation-technology/aluminum-casting>